PB-229 661

RAPPAHANNOCK RIVER INVESTIGATION IN THE VECINITY OF THE PROPOSED SALEM CHURCH RESERVOIR. ECONOMIC BENEFITS OF LOW-FLOW CONTROL FOR POLLUTION ABATEMENT IN THE RAPPAHANNOCK RIVER BASIN

Richard A. Vanderhoof, et al

Environmental Health Center
Cincinnati, Ohio

February 1952

DISTRIBUTED BY:

NTIS

National Technical Information Service
U. S. DEPARTMENT OF COMMERCE
5285 Port Royal Road, Springfield Va. 22151

PB 229 661

FEDERAL SECURITY AGENCY
Public Health Service
Environmental Health Center
Cincinnati, Ohio

RAPPAHANNOCK RIVER INVESTIGATION

in the vicinity of the Proposed

SALEM CHURCH RESERVOIR

Economic Benefits of Low-Flow Control for Pollution Abatement in the Rappahannock River Basin

PROPERTY OF:
U.S. DEPT. OF THE INTERIOR
FWPCA - Reference Service
633 Indiana Avenue, N.W.

By

Richard A. Vanderhoof
Public Health Engineer
Environmental Health Center
and
Charles M. Weiss
Biologist
North Atlantic Drainage Basins Office

Prepared by the Environmental Health Center and the
North Atlantic Drainage Basins Office, Public Health Service
at the request of and in cooperation with the
District Engineer, Corps of Engineers, U.S.Army, Baltimore, Maryland

Reproduced by
NATIONAL TECHNICAL
INFORMATION SERVICE
U S Department of Commerce
Springfield VA 22151

76

TABLE OF CONTENTS

	Page
INTRODUCTION	1
CONCLUSIONS	3
DESCRIPTION - BASIN DEVELOPMENT AND PROJECT	7
General	7
Economic Development	8
Location of Proposed Salem Church Project	8
Elevations (Feet above mean sea level)	9
SURVEY METHODS	10
General	10
Sampling Procedure	14
Laboratory Determinations and their Significance	14
PRESENTATION OF DATA	17
Use of Water Resources	17
Sources of Pollution	18
Planned Pollution Control	19
Laboratory Results	20
Temperatures	23
Hydrometric Data	25
DISCUSSION	27
General	27
Stream Flow	27
Present Conditions	28
Reservoir Influence on Water Quality	31
Temperature Stratification - General	31
Reaeration	34

LIST OF FIGURES

FIGURE 1 - Sources of Pollution, Water Supply Intakes, Location of Sampling Stations and Laboratory Data - Follows Page 11

FIGURE 2 - Vicinity and Location Map - Location of Sampling Stations Follows Figure 1

LIST OF TABLES

TABLE 1 - Required Minimum Discharges 6

TABLE 2 - Designation and Location of Sampling Stations 12

LIST OF TABLES

	Page
TABLE 3 - Designation and Location of Sampling Substations	13
TABLE 4 - Summary of Laboratory Results	21-22
TABLE 5 - Air and Water Temperatures	24
TABLE 6 - Flow Frequency	26
TABLE 7 - Low Flows of Record	26

LIST OF APPENDIXES

APPENDIX A - Laboratory Data, Tabulation of Individual Results	36
APPENDIX B - Mean Daily Discharges During Survey Period	45
APPENDIX C - Waste Treatment Plant Calculation of Table 1	47
APPENDIX D - Biology Report	52

Introduction

The Office of the District Engineer, Baltimore District, Corps of Engineers, in a letter dated 11 September 1951, requested that the Public Health Service make a field study of the Salem Church reservoir project.

The purpose of this study was the determination of the necessary pollution control releases from the proposed Salem Church, Virginia, reservoir project. This study was to be accomplished by assigning a mobile laboratory and necessary field crew to work on the Rappahannock River in the vicinity of Fredericksburg Virginia, for a sampling period of about three weeks. The work was to include the collection of water samples from the Rappahannock River above and through the reservoir area and in the tidal estuary below Fredericksburg to determine the effect of existing pollution on the stream. Data were to be gathered on the existing sewage pollution from Fredericksburg and on industrial waste pollution in the area. Information was to be obtained on any anticipated changes in industry and planned pollution abatement.

The field work was completed on October 17, 1951. The data obtained, a tabulation of necessary releases from the reservoir, and the conclusions drawn are presented in this report.

A previous report of this problem was made in June 1943, at the request of the District Engineer, U. S. Engineer Office, Washington, D. C. The investigation made at that time was necessarily brief, due to lack of personnel. Conditions in the vicinity of Fredericksburg have changed since that date, i.e., the City has grown in size, increasing the sewage pollution load, and industry has expanded, increasing industrial waste pollution loads on the Rappahannock River.

Industry and the several interested governmental agencies aided materially the conduct of the field study. The Sylvania Division of the American

Viscose Corporation provided data on the Rappahannock River collected during a survey made in the year 1950. The Virginia Fisheries Laboratory identified sampling points used by that agency and the American Viscose Corporation, thus enabling information collected by this field study to be compared directly with similar information from previous surveys. The Officer in Charge, North Atlantic Drainage Basin Office, Division of Water Pollution Control, Public Health Service, assisted by providing the biologist for the survey, and in establishing and maintaining liaison between the field survey personnel and co-operating agencies. The Virginia Water Control Board made the necessary arrangements for an interview with the principal industry in the area, and provided copies of data relevant to the Rappahannock Basin. The Virginia State Department of Health made the necessary preliminary arrangements for mobile laboratory parking facilities. The City of Fredericksburg, Virginia, provided the parking space and all utilities required for the mobile laboratory. The U. S. Geological Survey supplied river discharge records. The Virginia Electric and Power Company computed and supplied data on releases from their power plant during the survey period. The District Engineer, Baltimore District, provided the necessary boat and crew for sampling in the tidal estuary, and stream data. This co-operation is gratefully acknowledged.

Conclusions

1. The Rappahannock River above Fredericksburg and the Rapidan River were in good sanitary condition. The waters have a high dissolved oxygen content, low biochemical oxygen demand, and a low coliform M.P.N. index.

2. The Rappahannock River below Fredericksburg for a distance of approximately ten miles was in very poor sanitary condition. During the survey period, the stream had a septic zone (zero dissolved oxygen) which varied from 2.8 to 5.2 miles long, a high biochemical oxygen demand, and a high coliform M.P.N. index.

3. The impoundment of the Rappahannock River by the Salem Church project can be expected to reduce the dissolved oxygen content of waters released through the penstocks to about zero p.p.m. during the critical summer months. It is also expected that, through the reaeration process, the water will recover oxygen to 75% of its dissolved oxygen saturation value before it discharges into the tidal section of the Rappahannock River. This calculation was based upon existing impoundment conditions downstream and would not be valid for any other condition.

4. A <u>minimum continuous</u> flow of 200 c.f.s. should be released to the upper tidal reach of the river at all times in order to provide flow adequate for water supply purposes and to achieve benefits credited to the project for industrial water supply ($15,000 annually). With presently existing pollution loads, it would be desirable, if at all possible, to provide release in excess of the aforementioned minimum releases during week-end off-peak power periods; the specified 200 cfs

minimum release in combination with the partially re-regulated peaking power releases would provide some improvement over existing natural low-flow conditions insofar as stream water quality is concerned. (See following conclusions).

5. Consideration of the existing pollution loads and existing low stream flows under natural conditions at Fredericksburg indicates the need for secondary treatment of domestic sewage and equivalent correction of industrial wastes if the Rappahannock River is to be restored to a satisfactory sanitary condition.

6. Provision of waste treatment facilities which will insure a reduction of the existing downstream B.O.D. pollution load by at least 85%, along with minimum releases to the upper tidal reach of the river ranging from 200 c.f.s. in winter to 400 c.f.s. in summer as presented in schedule A (table 1), would produce satisfactory sanitary conditions in the Rappahannock River below Fredericksburg.

7. Increasing the low flows to 300 c.f.s. in the winter and 800 c.f.s. in the summer, in accordance with schedule B (table 1), will permit satisfactory conditions to be attained with a correction corresponding to a 70% B.O.D. reduction of the existing pollution load. Tangible annual monetary benefits in the form of decreased treatment costs with this regulation total $18,500.

8. Further increase in low flows to 400 c.f.s. in winter, and 1800 c.f.s. in summer, in accordance with schedule C (table 1), will permit satisfactory conditions to be attained with a correction corresponding to a 35% B.O.D. reduction of the existing pollution load. Tangible annual monetary benefits in the form of decreased treatment costs with this regu-

lation total $39,200.

9. As a matter of practical operation, flows during certain months may be in accordance with schedule B, while in more favorable months, schedule C will be readily attainable. With such operation, 35% reduction can be practiced during schedule C months using a chemical treatment plant (corresponding to a 70% B.O.D. reduction) without the addition of chemicals. Thus if flows in accordance with schedule C are maintained during part of the year, and flows in accordance with schedule B are maintained during the balance of the year, tangible monetary benefits will total $18,500, plus $1200 for each month that schedule C flows are maintained.

10. To achieve the purposes and the benefits indicated, the specified rates of release to the tidal section of the river must be reasonably continuous and uniform over the twenty-four (24) hour period.

11. When sewage treatment facilities are built by the city of Fredericksburg and/or the industrial waste load is reduced, a reanalysis should be made to determine the most satisfactory operation of the reservoir to meet all existing needs.

12. No appreciable hardness benefits can be credited to flow regulation because the Fredericksburg filtration plant records indicate that the Rappahannock River water is relatively soft, even during periods of low flow.

Table 1

Rappahannock River Investigation

Estimated Minimum Daily Discharges Required for All Months to Prevent Damage and to Secure Certain Tangible Benefits to Pollution Abatement in the Rappahannock River below Fredericksburg, Virginia

Estimated Minimum Daily Discharges by Month in Cubic Feet Per Second in the Rappahannock River Below Fredericksburg, Virginia

Month	Monthly * Average Temperature °C.	Secondary Treatment (Releases Necessary to Prevent Damage) Schedule A	To Secure Indicated Benefits: Chemical Treatment Schedule B	To Secure Indicated Benefits: Primary Treatment Schedule C
January	9.0	200	300	400
February	8.0	200	300	400
March	11.0	200	300	500
April	18.0	200	350	700
May	22.5	250	500	1000
June	28.0	400	800	1700
July	28.5	400	800	1800
August	28.5	400	800	1800
September	25.5	300	600	1300
October	20.0	200	400	800
November	12.0	200	300	500
December	5.5	200	300	400
Annual Average (Rounded)		260	480	940
Annual Benefits		None	$18,500.00	$39,200.00

For Mixed Schedule B and C
$18,500.00 plus $1200.00
per Schedule "C" Month

All schedules based upon existing conditions downstream from proposed dam site

* Maximum monthly average for period 1941-1950

Description

General

The Rappahannock River Basin is bounded on the north and west by the Potomac River Basin, on the east by Chesapeake Bay, and on the south by the York and the James River Basins.

The total drainage area of the Rappahannock River Basin is about 2948 square miles and lies entirely within the State of Virginia.

The headwaters of the Rappahannock River and those of its principal tributary, the Rapidan, lie on the eastern slopes of the Blue Ridge Mountains. The river flows in a generally easterly direction across the Piedmont Plateau and the Coastal Plain to Chesapeake Bay. The Rappahannock is tidal up to the "fall line" which is located very close to the City of Fredericksburg.

The climate of the basin is classed as humid, with the average annual rainfall varying from 41 to 46 inches. Except for summer storms, the rainfall is rather evenly distributed throughout the year. The mean annual temperature varies from 55 to 58°C. and the growing season averages about 250 days.

The total population of the basin according to the census of 1950 was about 110,740. Thirteen per cent of that population was urban.

Economic Development

The largest community within the basin is Fredericksburg, with a 1950 population of 12,143. Other major communities, with their 1950 populations, are as follows: Orange (2571), Culpeper (2527), Warrenton (1797), and Tappahannock (1011).

Farming is the chief economic activity of the basin, with livestock and poultry raising, dairying and truck crop farming being the principal types. Industries are relatively few and scattered. These include a large organic chemical industry at Fredericksburg and a number of canneries and other food processing plants. Oystering and fishing are the major source of livelihood for the majority of the people in the coastal counties.

Location of Proposed Salem Church Project

The Salem Church dam site is located about six miles upstream from Fredericksburg and the head of tidewater. The drainage area of the basin above the dam site is about 1590 square miles. The proposed reservoir will cover portions of Spotsylvania, Stafford, Culpeper, Orange, and Fauquier Counties.

The reservoir is proposed to be a dual purpose impoundment for flood control and hydroelectric power. Controlling elevations are as follows:

ELEVATIONS (Feet above mean sea level)

Flood-control-pool	239.5
Power-pool	220.0
Spillway Crest	204.5
Minimum power-pool	171.0
Approximate centerline of penstock intakes	142.0
Stream bed elevation at dam site	60+

Survey Methods

General

The primary objective of the field investigation was the collection of stream quality data, related information regarding sources of pollution and water uses, and stream flow data for the purpose of determining the existing degree of pollution in the Rappahannock River in the vicinity of Fredericksburg. From these data, the necessary releases to the upper tidal reach of the river for pollution abatement were to be determined. The sampling was scheduled for September and October to obtain data representative of low stream flow conditions and high water temperatures when the dissolved oxygen capacity in the stream would be at a minimum. During the field study, 134 samples were collected from 14 sampling stations. In addition, 74 samples were collected from substations between some of the regular sampling stations to determine critical points on the oxygen sag curve. Actual field operations were started on September 26 and continued through October 17.

Stream sampling stations were established above and below Fredericksburg since the main sources of pollution are from the Fredericksburg sewers and from a large organic chemical industry about one-half mile downstream from the Fredericksburg sewer outfall.

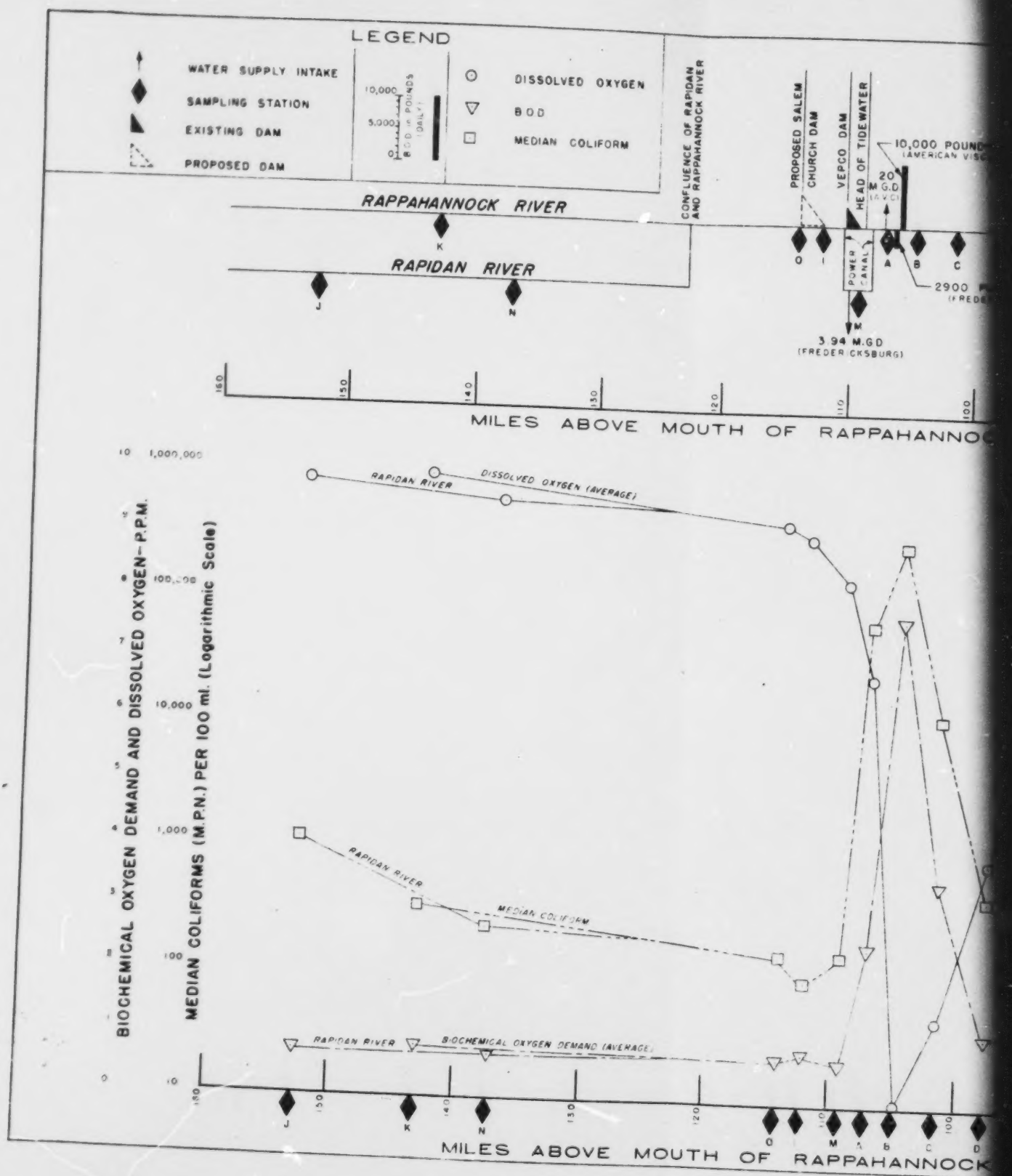
Six sampling stations were established above Fredericksburg, three on the main stream, two on the Rapidan River, and one on the Virginia Electric power canal in Fredericksburg. One sampling station on each stream was located above the reservoir area in order that a check might be made in the future of comparable qualities of waters flowing into the completed reservoir. The sampling station furthest upstream was about 39 miles above the dam site. All but two of these upstream samples were collected from bridges at the midpoint of the stream at a depth of 1 to 3 feet below the surface.

Below Fredericksburg, the eight sampling stations were identical to those used by the Virginia Fisheries Laboratory in order to take advantage of all available data previously collected from the river. Stations were established from the Fredericksburg Dock to Port Royal, a distance of about 30 miles. These samples were collected from a U. S. Engineer boat, the "Pocomoke," at a point as near midstream as the boat channel would permit. Samples were collected from two depths, one at 3 feet below the surface and another at a depth of 10 to 12 feet. The purpose of the sample from the greater depth was to determine if there was any stratification of chlorides due to tidewater.

The designations and locations of the sampling stations established for this investigation are shown in Table 2. Locations of sampling sub-stations are shown in Table 3. The sampling stations below Fredericksburg can be easily identified on the U. S. Coast and Geodetic Survey Chart of the Rappahannock River, Marsh Point to Fredericksburg.

Figure 1 represents graphically the location and extent of sources of pollution, the location of existing water intakes, the location of sampling points, and the location of existing and proposed dams.

Figure 2 is a location and vicinity map which shows the relative locations of the several points of interest.


LEGEND
WATER SUPPLY INTAKE
SAMPLING STATION
EXISTING DAM
PROPOSED DAM
10,000
5,000
0
B.O.D. in POUNDS DAILY
DISSOLVED OXYGEN
B.O.D.
MEDIAN COLIFORM
CONFLUENCE OF RAPIDAN AND RAPPAHANNOCK RIVER
PROPOSED SALEM CHURCH DAM
VEPCO DAM
HEAD OF TIDEWATER
10,000 POUND
(AMERICAN VISC
20
M.G.D
(A.V.C.)
RAPPAHANNOCK RIVER
RAPIDAN RIVER
K
J
N
O
I
POWER CANAL
A
B
C
2900
(FREDE
M
3.94 M.G.D
(FREDERICKSBURG)
160
150
140
130
120
110
100
MILES ABOVE MOUTH OF RAPPAHANNOC
BIOCHEMICAL OXYGEN DEMAND AND DISSOLVED OXYGEN - P.P.M.
MEDIAN COLIFORMS (M.P.N.) PER 100 ml. (Logarithmic Scale)
10
1,000,000
100,000
10,000
1,000
100
10
0
RAPIDAN RIVER
DISSOLVED OXYGEN (AVERAGE)
RAPIDAN RIVER
MEDIAN COLIFORM
RAPIDAN RIVER
BIOCHEMICAL OXYGEN DEMAND (AVERAGE)
J
K
N
O
M
A
B
C
D
MILES ABOVE MOUTH OF RAPPAHANNOCK

11. a

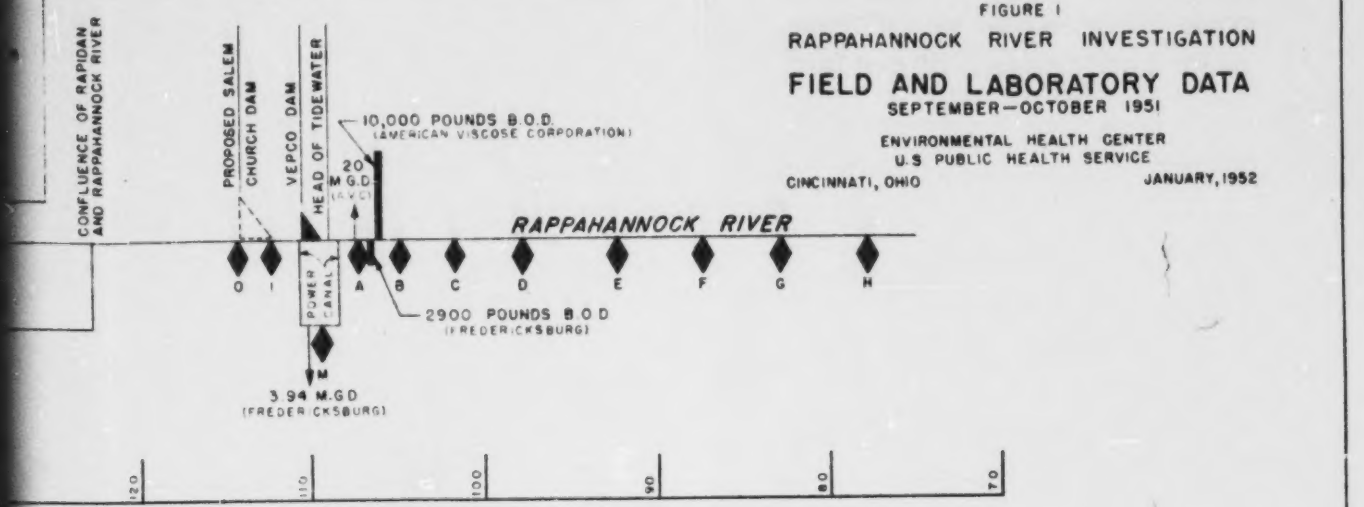
FIGURE 1

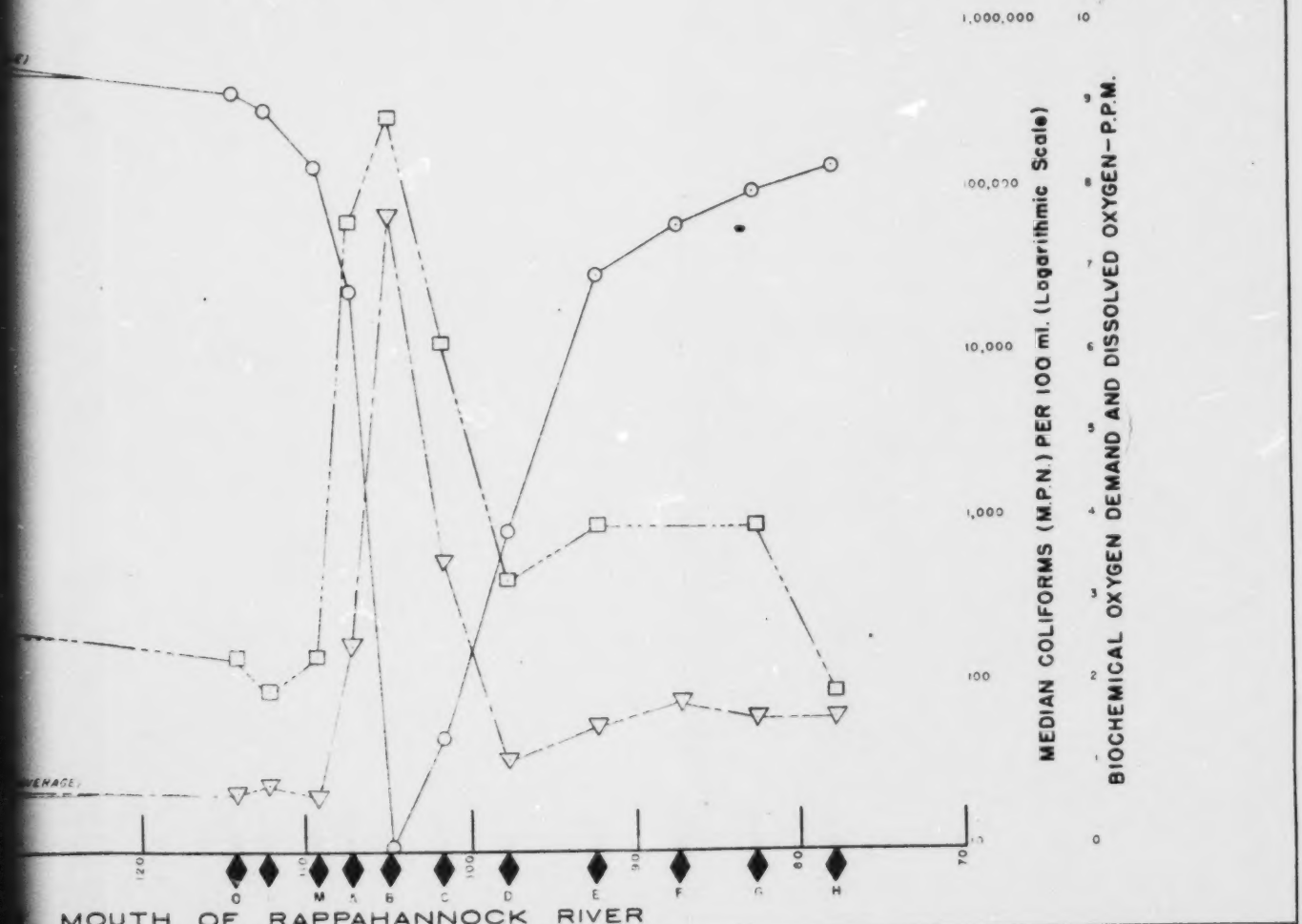
RAPPAHANNOCK RIVER INVESTIGATION

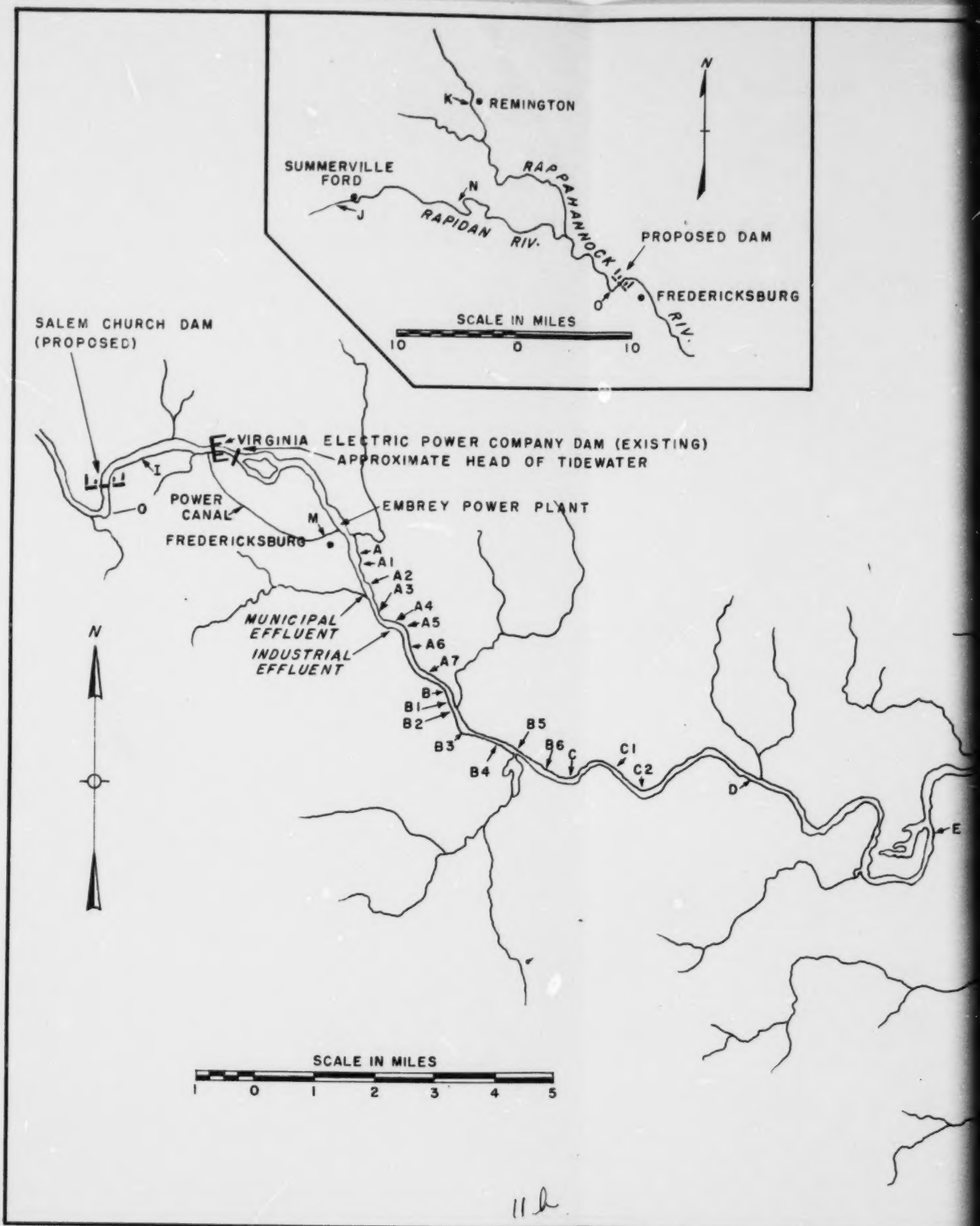
FIELD AND LABORATORY DATA

SEPTEMBER—OCTOBER 1951

ENVIRONMENTAL HEALTH CENTER
U.S PUBLIC HEALTH SERVICE
CINCINNATI, OHIO JANUARY, 1952


CONFLUENCE OF RAPIDAN AND RAPPAHANNOCK RIVER
PROPOSED SALEM CHURCH DAM
VEPCO DAM
HEAD OF TIDEWATER
10,000 POUNDS B.O.D. (AMERICAN VISCOSE CORPORATION)
20 M.G.D. (A.V.C.)
RAPPAHANNOCK RIVER
POWER CANAL
O I A B C D E F G H
2900 POUNDS B.O.D (FREDERICKSBURG)
M
3.94 M.G.D (FREDERICKSBURG)
120 110 100 90 80 70
MOUTH OF RAPPAHANNOCK RIVER




N
K
REMINGTON
SUMMERVILLE FORD
J
N
RAPIDAN RIV.
RAPPAHANNOCK RIV.
PROPOSED DAM
O
FREDERICKSBURG
SCALE IN MILES
10 0 10
SALEM CHURCH DAM (PROPOSED)
VIRGINIA ELECTRIC POWER COMPANY DAM (EXISTING)
APPROXIMATE HEAD OF TIDEWATER
I
L
POWER CANAL
O
M
EMBREY POWER PLANT
FREDERICKSBURG
A
A1
A2
A3
A4
A5
A6
A7
MUNICIPAL EFFLUENT
INDUSTRIAL EFFLUENT
B
B1
B2
B3
B4
B5
B6
C
C1
C2
D
E
N
SCALE IN MILES
1 0 1 2 3 4 5

11h

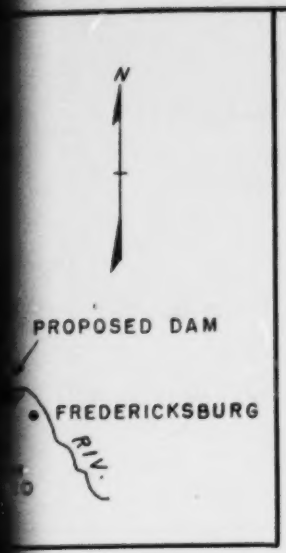
FIGURE 2

RAPPAHANNOCK RIVER INVESTIGATION

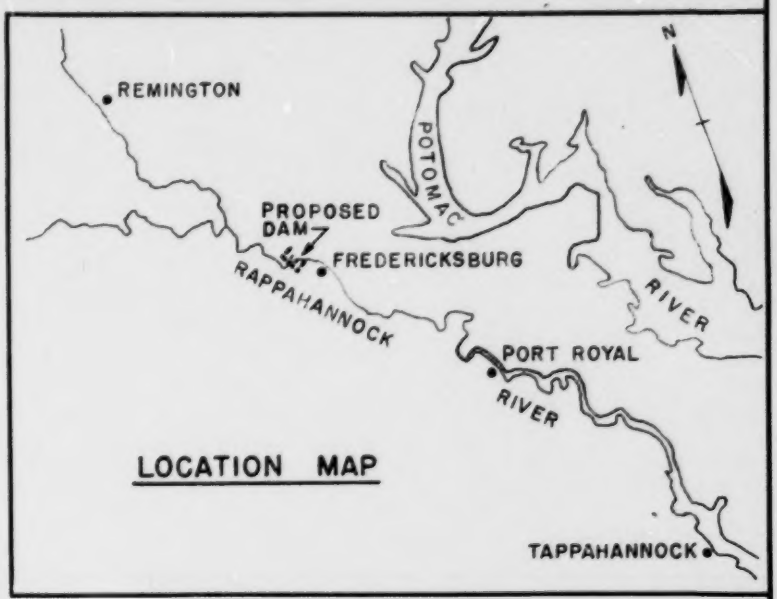
SAMPLING STATIONS & DAM SITE LOCATION & VICINITY MAPS

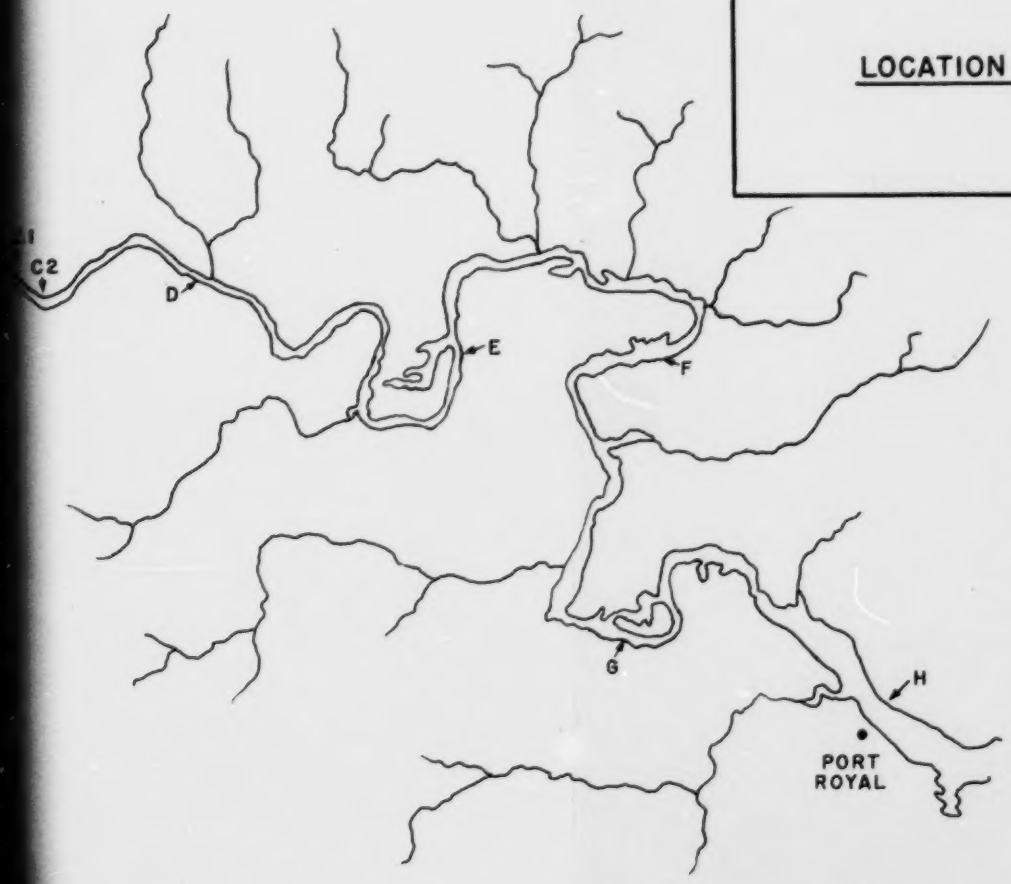
ENVIRONMENTAL HEALTH CENTER
U.S. PUBLIC HEALTH SERVICE

CINCINNATI, OHIO — JANUARY, 1952



(XISTING)
ER





LEGEND

SAMPLING STATION	B→
PROPOSED DAM	
EXISTING DAM	E

Table 2 - Rappahannock River Investigation - Designations and Locations of Sampling Stations

Station	River Mileage	Description
A	(107.2)	Rappahannock River (1) Head of navigation on Rappahannock River, about 200 ft. downstream from R.F.& P.RR. bridge in Fredericksburg, Va.
B	(104.8)	Rappahannock River (1) Newton's Rock - Rocks are visible only at low tide.
C	(101.6)	Rappahannock River (1) Belvedere - Barn on top of south bank.
D	(97.7)	Rappahannock River (1) Hayfield wharf - About midway between the two sets of old wharf piling on south shore.
E	(92.3)	Rappahannock River (1) Approximately 200 yards upstream from the month of Corbins Neck Creek and about 800 yards upstream from Spar 72.
F	(87.3)	Rappahannock River (1) Approximately 600 yards upstream from Spar 66 and about 150 yards upstream from opening to White Marsh on Buckners Neck.
G	(82.7)	Rappahannock River (1) Approximately 100 yards downstream from thorofare north of Goat Island.
H	(77.9)	Rappahannock River (1) Approximately 200 yards downstream from Port Royal bridge.
I	(112.2)	Rappahannock River (1) At the USGS gaging station above Fredericksburg, Va.
J	(29.6)	Rapidan River (2) U. S. Highway 522 bridge over Rapidan R. 10 miles from Culpeper, Va.
K	(143.1)	Rappahannock River (1) U. S. Highways 15 and 29 bridge over Rappahannock R. near Remington, Va.
M	(109.3)	Virginia Electric Power Company Canal (1) On Fall Hill Avenue bridge over the Virginia Electric Power Company canal.
N	(14.2)	Rapidan River (2) On State Route 3 highway bridge over the Rapidan R. near Wilderness.
O	(114.2)	Rappahannock River (1) Approximately 2000 ft. upstream from the proposed dam site.

(1) Miles above mouth of Rappahannock River.
(2) Miles above mouth of Rapidan River.
(3) Mouth of Rapidan River is 123.0 miles above mouth of Rappahannock River.

Table 3 - Rappahannock River Investigation - Designation and Locations of Sampling Substations on the Rappahannock River

Station	River Mileage	Description
A	107.2	Head of navigation near Fredericksburg.
A-1	106.9	At American Viscose Company old intake structure.
A-2	106.6	Opposite mouth of Hazel Run.
A-3	106.4	Point halfway between Hazel Run and American Viscose Company outfall.
A-4	106.2	American Viscose Company outfall.
A-5	105.9	Opposite old bulkhead.
A-6	105.5	Beginning of new bulkhead.
A-7	105.2	Beginning of new bulkhead.
B	104.8	Newton's Rock.
B-1	104.4	Point halfway between Newton's Rock and Fall Run.
B-2	104.1	Opposite Fall Run.
B-3	103.6	Epson Turn.
B-4	103.0	Opposite Massaponax Gravel Co. dock.
B-5	102.6	Opposite Massaponax Creek.
B-6	102.0	End of bulkhead at Spotswood Bar.
C	101.6	Belvedere.
C-1	101.0	Beginning of bend at Snowden bar.
C-2	100.4	Start of bulkhead at Fox Spring bend.
C-3	99.0	Opposite old dock at Castle Ferry bar.
D	97.7	Mayfield wharf.

Sampling Procedure

Samples were collected daily, from as many stations as circumstances would permit, to a maximum of 12 samples. No station was ever sampled more than once daily. The set of individual samples taken at each station consisted of standard bottles for dissolved oxygen, biochemical oxygen demand, coliform density, and a one-quart portion for other chemical analyses.

The sample collector recorded for each sample such field data as time of day sample was collected, important because of the necessity of determining the stage of the tide; air temperature and water temperature, and pertinent remarks regarding unusual stream conditions at the place of sampling. Samples were transported in ice-cooled carrying cases and subjected to analysis on the same day as received at the laboratory. Laboratory determinations were started within 6 hours after collection of a sample.

Laboratory Determinations and Their Significance

Routine laboratory tests were considered adequate to evaluate the sanitary quality of the streams in this area. The tests included those for dissolved oxygen, biochemical oxygen demand, coliform group organisms, pH, temperature, and chlorides. The significance of each test in evaluating the sanitary quality of a stream is discussed below.

Temperature - The temperature of water controls the oxygen solubility and thus the saturation level of dissolved oxygen in the stream. The rate of natural purification and bacterial growth is increased or diminished with higher or lower temperatures, respectively.

pH - pH is defined as the negative logarithm of the hydrogen ion concentration. The pH value indicates the relative acidity or alkalinity of a water, with the neutral point at pH 7.0. Values lower than 7.0 indicate the

presence of acid salts and, from pH 7.0 to 14.0, the presence of alkalies or alkaline earth salts is indicated.

Chloride - Chloride is present in all natural waters, being particularly prevalent near the ocean and in the vicinity of salt deposits. The chloride content of a stream in many cases can be used as an indication of the entrance of domestic sewage or trade wastes. The presence of more chloride in a sample of water than would be normal for the region is a strong indication of contamination from outside sources. In this instance, the chloride test was also used to establish limits of salt water intrusion into the estuary and to determine completeness of mixing during the tidal cycle.

Dissolved Oxygen (D.O.) - Normally the amount of oxygen dissolved in water of a stream is limited by the saturation value (9.17 p.p.m. at 20°C) which is a function of water temperature, but in some cases, as result of the photosynthetic action of some water plants, this value may be exceeded, causing "supersaturation." The saturation value decreases with higher temperatures. To support fish and aquatic life and for natural aerobic purification of stream waters, dissolved oxygen must be present. The minimum quantity permissible is dependent on the quality of the water desired and stream flows. Dissolved oxygen must be present to prevent nuisance conditions associated with putrefactive decomposition of waste materials in a stream. Dissolved oxygen values below the saturation level are an indication of the presence of organic pollution which is utilizing oxygen from the stream water. A measure of the effect of pollution of a particular area is given by the deficiency in the dissolved oxygen content below saturation. The minimum quantity of dissolved oxygen in a river of satisfactory sanitary quality is 5.0 p.p.m.

Biochemical Oxygen Demand (B.O.D.) - The biochemical oxygen demand (frequently referred to as B.O.D.) of sewage, sewage effluents, polluted

waters, or industrial wastes is the oxygen (in parts per million) required during stabilization of the decomposable organic matter by aerobic bacterial action. Complete stabilization requires more than 100 days at 20°C, but such long periods of incubation are impracticable in any but research investigations. Consequently a much shorter period of incubation is used. Incubation for 5 days at 20° C is recommended as the standard procedure and this recommendation was followed during the field study. Conversion of the data from one incubation period to another, or from one temperature to another, may be approximated.

As the amount of dissolved oxygen present decreases with rising temperatures, and at the same time the rate of biochemical oxidation increases as the temperature rises, critical stream conditions usually result during warm months, particularly since these high temperatures are often associated with low stream flows.

Coliform Group Organisms - This determination is a sensitive indicator of sewage pollution, since it shows the approximate density of organisms that are normally found only in very small numbers in unpolluted streams. Coliform bacteria are normally present in the intestines of warm-blooded animals and are discharged in vast numbers in human feces, which constitute the main source of these bacteria in sewage. The coliform density is usually measured as "most probable number" (M.P.N.) of organisms per 100 milliliters of sample. This method of reporting the results of examinations is commonly known as the "M.P.N. Index."

The bacteriological examinations and chemical analyses were made in accordance with "Standard Methods for the Examination of Water and Sewage," Ninth Edition, 1946, A.P.H.A.

Presentation of Data

Use of Water Resources

There are fifteen public water supplies in the basin, serving a population of about 21,900. Three of these, serving 17,250 people, are surface supplies, the largest of which is Fredericksburg, serving over 12,600 people. The other two communities using surface supplies, Orange and Culpeper, are located upstream from the reservoir area.

The raw water supply of the City of Fredericksburg is taken from the Rappahannock River, passed through the Virginia Electric Power Company canal and drawn off from the canal at the city filtration plant. The water requirements of Fredericksburg during 1950 varied from 5.37 M.G.D. to 3.01 M.G.D., with an annual average of 3.94 M.G.D.

Large quantities of river water are used by an organic chemical plant located on the Rappahannock River downstream from Fredericksburg. The maximum pumpage of river water is expected to be 36 M.G.D. at the completion of the expansion program. The raw water intake is located in Fredericksburg, a short distance downstream from the R.F.& P. RR. bridge in tidewater, and approximately at sampling station "A."

The Virginia Electric Power Company has a low dam across the Rappahannock River at a point about three miles downstream from the proposed Salem Church dam site. At the VEPCO dam, there are diversion works which divert water through a two-mile-long power canal to the Embrey Power Plant of VEPCO. The power station is located on the Rappahannock River in Fredericksburg, on tidewater.

The power station is designed to use about 50 ft. of head and about 1000 c.f.s. The station is operated as a straight run-of-river plant, maintaining

practically constant elevation in the pond. During periods of low flow, i.e., less than 1000 c.f.s., the entire river discharge is routed through the power canal and the discharge from the station is almost identical with the river flow during this period, when no water is passing over the dam. It is possible for the entire low river flow to be detained for short intervals of time measured in hours, permitting no water to enter the tidewater section of the Rappahannock.

Valuable commercial fisheries exist below Port Royal and along adjacent shores in Chesapeake Bay. The river is a spawning ground for several varieties of commercial fish. During the spring, it is especially important for the river to flow in a non-brackish condition below Port Royal at the spawning grounds.

Sources of Pollution

Twelve municipalities discharge pollution to watercourses of the basin. Eight of these, serving 20,920 people, discharge sewage reduced by treatment to a population equivalent of 15,975. With the exception of the City of Fredericksburg, these communities are located outside of the area of sampling. The laboratory determinations made from samples collected from water flowing into the proposed reservoir area gave results which indicated no appreciable sewage pollution effects.

Fredericksburg is the only incorporated community in the Rappahannock River basin which discharges sewage without treatment. Raw sewage is discharged into the Rappahannock in the vicinity of Hazel Run. The daytime sewage flow was estimated to be about 2.9 M.G.D.,[1] while the nighttime flow was estimated to be about 0.9 M.G.D. The average flow of sewage on a 24-hour basis was estimated

---

(1) Sewage flow and strength data were obtained from a Consulting Engineer's Report to the City of Fredericksburg.

to be about 2.2M.G.D. The average B.O.D. was estimated to be 157 p.p.m. The sewage flows from Fredericksburg include all industrial wastes from within the corporation limits. From these data, the total B.O.D. load from the Fredericksburg sewers amounts to about 2900 pounds per day.

Eleven industries discharge waste directly into the Rappahannock or into streams tributary to it. However, there were no industries within the area of sampling except those on the Fredericksburg sewers, and the organic chemical plant downstream. As the industrial wastes from within Fredericksburg were included with Fredericksburg sewage, only the chemical plant need be considered. The B.O.D. load from the chemical plant was computed to be about 10,000 pounds per day.

The Fredericksburg sewer outfall and the industrial plant outfall are about one-half mile apart and on a tidewater river. Since the outfalls are close together and since tidewater action mixes the two effluents, the influence of each on the river cannot be separately determined. Together, there is here discharged a pollutional load with a population equivalent of about 76,000 or about 95 per cent of the total known pollutional load of the river basin.

Planned Pollution Control

Industrial plants in Virginia which were discharging wastes without treatment prior to 1946 are, after certification by the State Water Control Board, permitted to continue. On the other hand, the Board may require the owner "to adopt measures for the reduction of such pollution." Since no order has been issued to reduce the pollution load from the Sylvania plant, the date when this might be accomplished is very indefinite. The City of Fredericksburg has prepared a preliminary engineering report on sewage treatment which has been approved by the Board. However, the Board has not specified the ultimate degree of treatment required for the city's sewage. If the city provides primary treatment only, the B.O.D.

load on the Rappahannock River below Fredericksburg will be reduced from approximately 12,900 pounds daily to approximately 11,900 pounds daily.

Laboratory Results

The laboratory results obtained during the recent field survey have been summarized for each sampling station in Table 4. This table shows for each location the median and range of coliform densities and the average and range of values for the other determinations. The average dissolved oxygen from both sampling stations and substations are shown in Appendix A. The average dissolved oxygen values average B.O.D. data, and median coliform results for the Rappahannock River are presented in figure 1, together with locations of sources of pollution. A tabulation of individual daily results, together with corresponding stream discharge data, is presented in Appendix A.

Table 4
RAPPAHANNOCK RIVER SURVEY
Summary of Laboratory Results

Sampling Station		Stream Discharge (c.f.s.)	Water Temp. (°C.)	Dissolved Oxygen ppm	Dissolved Oxygen % Sat.	5-Day B.O.D. 20° C. ppm	Coliforms MPN per 100 ml.	Chloride ppm	pH
A	Med.		-	-	-	-	68,000	-	-
	Avg.	154	20	6.8	74%	2.5	-	3.2	-
	Max.		24	9.3		4.3	460,000	5.0	7.2
	Min.		13	3.7		0.9	4,900	1.2	6.7
B	Med.		-	-		-	280,000	-	-
	Avg.	"	20	0.1	1%	7.7	-	12.1	-
	Max.		25	0.7		11.7	11,000,000	14.3	6.6
	Min.		14	0		2.0	23,000	8.3	6.0
C	Med.		-	-	-	-	12,000	-	-
	Avg.	"	19	1.4	15%	3.5	-	10.8	-
	Max.		23	3.5		6.8	11,000,000	13.2	6.8
	Min.		15	0		0.9	91	7.2	6.1
D	Med.		-	-	-	-	430	-	-
	Avg.	"	20	3.9	43%	1.1	-	8.9	-
	Max.		23	4.9		1.4	2,300	10.7	7.0
	Min.		15	2.7		0.5	45	6.4	6.7
E	Med.		-	-	-	-	930	-	-
	Avg.	"	20	7.0	76%	1.5	-	7.5	-
	Max.		23	7.6		3.7	4,300	9.3	7.0
	Min.		15	6.6		1.0	40	5.1	6.7
F	Med.		-	-	-	-	930	-	-
	Avg.	"	21	7.6	85%	1.8	-	6.6	-
	Max.		24	8.1		5.6	4,300	7.6	7.1
	Min.		16	7.2		1.0	330	5.2	6.8
G	Med.		-	-	-	-	930	-	-
	Avg.	"	21	8.0	89%	1.6	-	7.4	-
	Max.		25	9.6		3.3	4,300	10.9	7.0
	Min.		16	7.6		0.9	170	4.4	6.8
H	Med.		-	-	-	-	140	-	-
	Avg.	"	21	8.3	92%	1.6	-	23.5	-
	Max.		26	8.7		1.9	430	32.6	7.1
	Min.		16	7.8		0.8	91	10.3	6.6

Table 4 (Cont'd)

RAPPAHANNOCK RIVER SURVEY

Summary of Laboratory Results

Sampling Station		Stream Discharge (c.f.s.)	Water Temp. (°C.)	Dissolved Oxygen ppm	Dissolved Oxygen % Sat.	5-Day B.O.D. 20° C. ppm	Coliforms MPN per 100 ml.	Chloride ppm	pH
I	Med.	-	-	-	-	-	91	-	-
	Avg.	154	18	9.0	94%	0.8	-	2.8	-
	Max.		22	10.4		1.1	230	5.0	7.2
	Min.		13	8.0		0.6	20	2.0	6.8
J	Med.	-	-	-	-	-	1,100	-	-
	Avg.	67	20	9.8	107%	0.7	-	2.2	-
	Max.		24	11.1		1.0	2,400	3.0	7.2
	Min.		14	8.8		0.5	230	1.5	6.9
K	Med.	-	-	-	-	-	330	-	-
	Avg.	46	20	9.9	108%	0.8	-	2.4	-
	Max.		26	10.4		1.2	1,300	2.9	7.2
	Min.		14	9.2		0.4	<20	1.9	6.8
M	Med.	-	-	-	-	-	150	-	-
	Avg.	154	19	8.3	89%	0.7	-	2.5	-
	Max.		22	9.0		1.0	430	4.1	7.1
	Min.		14	7.4		0.5	110	1.8	6.8
N	Med.	-	-	-	-	-	230	-	-
	Avg.	67	20	9.5	104%	0.7	-	2.7	-
	Max.		24	10.6		0.9	490	3.1	7.2
	Min.		14	8.2		0.5	91	2.1	6.9
O	Med.	-	-	-	-	-	150	-	-
	Avg.	154	18	9.2	96%	0.7	-	2.7	-
	Max.		24	10.4		1.0	930	4.8	7.2
	Min.		14	8.4		0.4	36	1.8	6.9

Temperatures

Air and water temperatures have a definite influence in pollution conditions, much higher flows being required during the hot summer months than during the colder months, if identical quantities of dissolved oxygen are to be maintained in the stream below a source of pollution. The annual average normal air temperature at Fredericksburg, according to the records of the Weather Bureau, has been 56.4 degrees Fahrenheit. Monthly normal air temperatures, average air temperatures for individual months, and corresponding average water temperatures taken from the Fredericksburg filtration plant records, are shown in Table 5.

Table 5
RAPPAHANNOCK RIVER SURVEY
Air and Water Temperatures (°F)

Month / Year	Jan.		Feb.		Mar.		Apr.		May		June	
	Air	Water	Air	Water	Air	Water	Air	Water	Air	Water	Air	Water
Normal	36.5		37.0		46.7		55.1		64.9		72.5	
1950	-	48	38.0	46	41.5	47	52.3	59	64.6	72	72.4	77
1949	44.0	42	42.7	45	45.3	47	54.3	56	65.1	71	74.1	80
1948	29.4	33	38.0	35	48.8	48	57.4	59	65.4	64	74.4	78
1947	42.2	40	31.8	36	38.0	40	57.2	57	64.7	67	70.4	74
1946	37.2	38	40.6	38	52.4	50	55.5	60	64.2	66	71.0	74
1945	32.2	34	38.8	37	56.0	52	58.5	64	61.6	63	72.3	77
1944	37.0	36	38.2	39	43.4	42	53.9	59	69.8	72	75.6	78
1943	37.4	40	39.4	39	45.4	45	51.6	53	66.8	68	77.6	82
1942	34.2	36	34.4	37	47.1	48	58.1	59	67.4	72	73.2	78
1941	34.2	41	34.0	36	39.7	45	58.5	61	65.8	72	72.4	77
Ten Year Average	36.4	37.7	37.6	38.8	45.8	46.4	55.7	58.7	65.5	68.7	73.3	77.5
Maximum		48		46		52		64		72		82

Month / Year	July		Aug.		Sept.		Oct.		Nov.		Dec.	
	Air	Water	Air	Water	Air	Water	Air	Water	Air	Water	Air	Water
Normal	76.6		75.1		69.3		57.9		47.4		37.9	
1950	75.2	83	74.8	82	66.7	73	60.1	63	45.8	54	33.3	42
1949	80.4	82	76.9	81	66.4	73	60.4	63	47.4	41	39.8	42
1948	78.1	80	-	75	69.3	72	55.4	55	51.4	53	39.4	38
1947	75.1	77	78.4	82	70.3	71	65.2	64	45.2	49	36.9	37
1946	73.8	80	70.8	76	68.7	73	60.2	62	51.6	52	41.9	40
1945	74.6	78	72.9	78	71.9	76	56.3	60	49.0	51	32.8	37
1944	77.0	81	74.0	83	69.4	72	55.7	58	46.2	47	34.0	36
1943	77.6	81	77.8	81	67.2	72	55.2	60	46.0	48	36.8	38
1942	77.6	82	73.6	78	68.6	72	58.8	58	49.0	50	34.8	39
1941	77.4	81	74.3	81	71.4	78	64.2	68	48.1	50	41.0	40
Ten Year Average	76.7	80.5	74.8	80.2	69.0	73.2	59.1	61.1	48.0	49.5	37.1	38.9
Maximum		83		83		78		63		54		42

Hydrometric Data

In stream pollution studies, low summer flows are of major interest because of the critical dissolved oxygen which may occur due to the combination of a pollutional load with low flows and high temperatures. For this reason, a brief study was made on the recurrence interval of low stream flows for the period of record.

The record of average monthly observed flows for June through September has been brought up to date, and based upon the 40 years of record from 1907 to 1947, the selected frequencies of flow for each critical month and combinations of consecutive months have been computed by the Corps of Engineers and are tabulated in Table 6.

Monthly mean summer flows at Fredericksburg for years in which lowest summer flows have occurred are presented in Table 7.

The U. S. Geological Survey records of the flow of the Rappahannock River and its principal tributary, the Rapidan, from gages at Culpeper, Kellys Ford, and Fredericksburg, were made available for the sampling period. These data are tabulated in Appendix "B."

Table 6

RAPPAHANNOCK RIVER SURVEY

MINIMUM MONTHLY MEAN FLOWS AT INDICATED AVERAGE INTERVALS OF PROBABLE OCCURRENCE
(Cubic Feet/second)

Month	2 years	5 years	10 years	20 years	50 years
June	975	620	535	500	460
July	870	480	385	310	205
August	770	410	270	165	90
September	620	250	190	150	75
Combination of Months					
July-August	1010	495	330	260	190
July-Aug.Sept.	1055	510	305	220	170

Note: Above data obtained from letter dated 20 Dec. 1948, from Corps of Engineers to U. S. P. H. S.

Table 7

RAPPAHANNOCK RIVER SURVEY

MONTHLY MEAN SUMMER FLOWS FOR YEARS OF RECORD DURING DURING WHICH LOWEST SUMMER FLOWS HAVE OCCURRED
(Cubic Feet/second)

Year	1930	1925	1932	1943	1936	1914	1931
Month							
June	343	588	588	766	512	523	601
July	78	390	357	407	467	518	545
August	21	225	135	111	277	275	579
September	46	154	59	167	198	164	261

Note: Above data obtained from U. S. G. S. records on a gaging station near Fredericksburg, Sampling Station I.

Discussion

General

The principal objective of pollution control activities is to maintain or restore a water quality which will be satisfactory for all normal water usage. The criteria of quality usually considered include the bacterial density, pH, dissolved oxygen content, amount of oils and floating solids, and the concentration of toxic and taste and odor producing compounds. Increased low-water flows provide additional dilution, under critical conditions, for the wastes received by a stream and thus help to provide more desirable conditions in the stream. In the Rappahannock River, the most important measure of stream quality is the dissolved oxygen content. For the purpose of this study, a dissolved oxygen content of 5 p.p.m. was selected. This is believed to be the lowest sustained oxygen level for the proper maintenance of a balanced aquatic life.

Stream Flow

In practically all streams, there is a wide variation in flow. The minimum daily flow of the Rappahannock River at Fredericksburg (5 c.f.s.) was 0.30 per cent of the average (1670 c.f.s.); and the minimum monthly flow (21.1 c.f.s.) was 1.26 per cent of the average. The amount of water available for dilution of wastes is an important factor, and since the dissolved oxygen content of the dilution water varies with the water temperature, and the pollutional loads are approximately constant daily, it is apparent that there is a wide variation in the magnitude of the pollution problem during a single year. During the period of this survey, river flows entering the estuary were unusually low, averaging 154 c.f.s. with a temperature of 19° C. With the effect of relatively high water temperatures added to those of low flows, the Rappahannock River was grossly

polluted for about ten miles below Fredericksburg, with zero dissolved oxygen for from 2 to 5 miles.* However, during cold weather and with flows of average magnitude (1670 c.f.s.) the dissolved oxygen content was observed by others to be greater than 5 p.p.m. A study of data obtained by the American Viscose Corporation during the summer of 1950 indicated that, with existing pollutional conditions, a flow of 1200 c.f.s. with a dissolved oxygen content of 90% saturation would be required to maintain a satisfactory dissolved oxygen level in the river below Fredericksburg.

Present Conditions

The Rappahannock River above Fredericksburg, during the sampling period, was in good sanitary condition. The dissolved oxygen content was found to vary from supersaturation (over 100%) at sampling station K to 89% at sampling station M. The coliform density ranged from a maximum of 1300 per 100 ml. to a minimum of 20 per 100 ml. The maximum B.O.D. observed was 1.0 p.p.m. The chlorides ranged from a maximum of 5.0 p.p.m. to a minimum of 1.5 p.p.m. The pH ranged from 6.8 to 7.2.

The Rapidan River, the principal tributary to the Rappahannock River, joins the Rappahannock River at a point about 9 miles upstream from the proposed dam site. This tributary was observed to be of good sanitary quality during the survey period. The dissolved oxygen content was found to be over 100% of saturation at both sampling stations. The coliform density ranged from a maximum of 2400 per 100 ml. to a minimum of 91 per 100 ml. The maximum B.O.D. observed was 1.0 p.p.m. The chlorides ranged from 3.1 p.p.m. to 1.5 p.p.m. The pH ranged from 6.9 to 7.2.

The water entering the tidewater section of the Rappahannock River was of good sanitary quality. During the survey period, the dissolved oxygen

*Figure 1 shows average values; not minima. See Appendix A, page 43.

content was 89% of saturation, i.e., 8.3 p.p.m. at 19°C., the maximum B.O.D. was 1.0 p.p.m., the median coliform density was 150 per 100 ml., chlorides averaged 2.5 p.p.m., and the pH ranged from 6.8 to 7.1.

The tidal estuary of the Rappahannock River may be considered in three reaches: the head of tidewater to the American Viscose Corporation, the American Viscose Corporation to a point approximately 10 miles downstream, and the remainder of the river to Port Royal.

The sanitary quality of the reach from the head of tidewater to the American Viscose Corporation was influenced by tides and river discharges during the survey period. During the strength of the ebb tide, the incoming water was carried downstream in a condition similar to that found upstream in nontidal waters. An increase in coliform density was noted even during ebb tide. This can possibly be attributed to the adjacent population in the upper tidewater reach. During the strength of the flood tide, raw sewage was carried upstream. This was noted at sampling station A by the increase in concentrations of B.O.D. and chlorides, and in the coliform M.P.N. index. While not observed during the survey period, it is apparent that high flows would keep the fresh water moving downstream regardless of the height of the tide. Tabulations of the individual results, together with tidal conditions and river discharges, are presented in appendix "A."

This reach was critical because it is the source of the industrial water of the American Viscose Corporation. The industrial water intake is located near sampling station A, about one mile upstream from the American Viscose Corporation outfall. One requirement of the industrial water quality is that none of its own industrial waste, which contains a large

amount of sulfates, may be present in the fresh water taken into the plant. Observations made by the American Viscose Corporation during the survey period showed that the industrial wastes were within 200-300 feet of the industrial water intake. Failure of the river to provide the necessary quality of industrial water would force a plant shutdown and would jeopardize the employment of about 2500 men.

The American Viscose Corporation is planning an expansion program. Upon the completion of that program, it will require 17 M.G.D. more than it is now using. It is probable that the City of Fredericksburg will increase in size with the industrial expansion, and will also require additional water.

With the above situation in mind, and considering that the average discharge of the Rappahannock River during the survey period was 154 c.f.s., it is recommended that a minimum continuous flow of 200 c.f.s. be released to the upper tidal reach of the river.

The waters of the reach from the American Viscose Corporation for a distance of approximately 10 miles downstream (sampling stations B and C) were grossly polluted during the survey period. Within this reach, a septic zone of from 2.8 to 5.2 miles long was observed, the length varying with the river discharge and tide. The coliform M.P.N. index ranged from 24,000 to 11,000,000 per 100 ml., the B.O.D. ranged from 2.0 to 12.7 p.p.m., the chlorides ranged from 7.2 to 14.3 p.p.m., and the pH ranged from 5.9 to 6.8. The above values also varied with the river discharge and the tide. Based upon the average river discharge during the survey period, and the average of high and low river volumes at sampling stations B and C, it was estimated that the pollution at B was 3 days ole while the pollution at C was 10 days old.

Beginning at sampling station D, Hayfield Wharf, the river enters a re-

covery zone. At sampling station D, the dissolved oxygen had recovered to 43% of saturation, the B.O.D. ranged from 0.5 to 2.2 p.p.m., the coliform M.P.N. index ranged from 45 to 2400 per 100 ml., the chlorides ranged from 6.4 to 10.7 p.p.m., and the pH ranged from 6.7 to 7.0. Downstream from sampling station D, the river continued to recover until at the last station sampled, H, Port Royal, the dissolved oxygen content had recovered to an average of 92% of its saturation value and the coliform M.P.N. index had decreased to a range of 91 to 430 per 100 ml. The B.O.D. and pH range continued to be approximately the same as observed at station D. The average chlorides had decreased from a value of 8.9 p.p.m. at D to 6.6 p.p.m. at sampling station F, and increased to 7.4 p.p.m. at sampling station G, and then showed a sharp increase between G and H, increasing from an average of 7.4 p.p.m. to 23.5 p.p.m. This increase in chlorides from sampling station F to sampling station H is probably due to salts from the ocean carried upstream by tidewater action.

The water quality at sampling station H can be favorably compared with the water quality at sampling station I, during the survey period. (Thus, the tidal section of the Rappahannock River has gone through the self-purification process in a period estimated to be about 90 days under survey conditions.

Reservoir Influence on Water Quality

Temperature stratification and the depletion of dissolved oxygen in the lower depths of a reservoir are explained in the following discussion.

Temperature Stratification - General - The ultimate reason for temperature stratification lies in variations in the density of water at different temperatures. The density of water is a maximum at 4°C. and decreases at both higher and lower temperatures. Though apparently slight,

the differences are sufficient to establish layers of lighter water overlying denser water. Since the temperature of water near the surface or entering the reservoir rises and falls with weather changes, major changes occur in the reservoir following a seasonal pattern.

Typical conditions are described as follows. Assume a lake in the spring of the year with water temperature throughout its depth of near 4 or 5°C. As the season progresses, the temperature of water near the surface of the reservoir rises. Such water of higher temperature, being less dense, will tend to remain in a layer above the cooler water in the deep part of the lake. However, as long as the temperature difference is not great, wind action will be sufficient to stir the waters in the reservoir throughout their depth. As the season further progresses, and calm weather prevails for a period, there is established a relatively stable condition of a layer of warm water overlying a layer of colder water, the warm layer having a density differential sufficient to resist forces tending to mix the layers. The temperature of the lower layer will depend on the wind and weather conditions which prevailed during the period when the surface water temperatures were increasing. Commonly, the temperature of the lower layer will be a few degrees above the temperature of maximum density.

The depth of the upper layer is typically from 20 to 40 feet. This upper layer, when further warmed, may establish a stratification in itself and may later be mixed again by convection currents or wind action. These minor variations result at times in a gradual decrease in temperature from the water surface to the upper strata of the low cold layer and, at other times, in a uniform temperature through the depth of the upper layers, followed by a sharp decrease in temperature to that of the lower layers. Convection and wind

currents are almost continuously at work mixing the upper stratum, resulting generally in uniform character throughout its depth. The lower layers generally remain practically stagnant. Stagnant water near the bottom of the lake, if sufficient organic matter is present, may become depleted of oxygen by bacterial action. Dissolved oxygen in the water is utilized by the bacteria in their life process to oxidize organic matter which may be present on the bottom of the reservoir when constructed or may settle out of waters entering the reservoir. Bacterial decomposition of the organic matter will continue after all the dissolved oxygen has been utilized. Under such anaerobic conditions, as organic matter is decomposed, most of its sulfur is reduced to free sulfur, hydrogen sulfide, mercaptans, and other sulfur compounds. These compounds are slightly soluble and will build up appreciable concentrations in the deoxygenated water. Anaerobic conditions are also important in their relation to iron and manganese.

In the fall, when cooler temperatures prevail, the water on the surface of the lake will be cooled and convection currents will mix it with the warmer layers below. As the season progresses, the temperature of the upper layer will approach that of the lower layer. Mixing action of the wind will then be able to stir the lake throughout its depth, a condition known as the fall overturn. Anaerobic conditions will be relieved by this action.

In severe climates, the waters near the surface may be cooled sufficiently below the temperature of maximum density to establish wintertime stratification, that is, with water at about 4°C. making up the bottom layer and water at 0° making up the upper layer. The temperatures prevailing in the vicinity of Fredericksburg are probably not low enough to produce such wintertime stratification.

Since it is expected that there will be stratification during the critical months of July and August, it is possible that the dissolved oxygen content of the water discharged from the proposed reservoir during this period may be zero. This possibility was confirmed by a study of samples of water drawn from the penstocks of various reservoirs of similar depth in the Tennessee Valley. Seven out of ten dams with reservoirs over 50 feet in depth showed a dissolved oxygen content of 1.0 p.p.m. or less.

Reaeration - If there were some assurance that even though water with zero oxygen content were to be discharged from the dam, reaeration would raise the dissolved oxygen content to 90% saturation, fewer restrictions on operation of the reservoir would be necessary to prevent damage downstream.

It is expected that the water discharged from the proposed Salem Church Reservoir will be very low in B.O.D., and therefore the reaeration will not be complicated by a concurrent B.O.D. To determine how much reaeration the reach below the dam can be depended upon to supply, a study was made of four investigations of reaeration below existing dams, and the data applied to the Salem Church Reservoir. From a study of the available investigations, it was thought that the reach below the dam could be depended upon to reaerate to 75 per cent of saturation. This figure was used in preparing table 1.

APPENDICES

APPENDIX A

TABULATION OF INDIVIDUAL RESULTS

RAPPAHANNOCK RIVER INVESTIGATION

Appendix "A"

Tabulation of Individual Results

Sampling Station & No.	Date	Time	Stream Discharge (cfs)	Water Temp. °C.	Dissolved Oxygen ppm	Dissolved Oxygen % Sat.	5-Day B.O.D. ppm	Coliforms MPN/100 ml.	Chlorides Depth 3'	Chlorides Depth 10'	pH Depth 3'	Time From h	Time From m
A					Ebb Tide								High Tide
124	10/12	8:30	200	15	8.1	79.8	-	-	-	-	-	3	43
17	9/28	9:00	139	19	7.3	78.1	1.8	11,000	2.0	-	7.0	4	07
111	10/11	8:30	200	15	8.0	78.8	-	-	-	-	-	4	46
100	10/10	8:15	163	13	7.5	70.8	0.9	23,000	1.2	-	6.7	5	40
12	9/27	10:50	166	23	7.2	82.9	2.6	4,900	2.2	-	7.0	6	47
					Flood Tide								Low Tide
89	10/9	8:30	160	15	7.6	74.9	1.4	43,000	3.0	-	7.0	0	6
78	10/8	8:40	144	20	6.3	68.7	1.8	93,000	3.0	3.0	7.1	1	11
43	10/3	16:40	155	22	9.3	105.3	3.3	43,000	3.8	4.2	7.2	1	53
67	10/6	8:20	160	23	3.7	42.6	4.2	240,000	5.0	5.0	6.7	3	6
56	10/5	8:20	132	22	7.0	79.3	1.5	460,000	4.2	4.1	7.2	4	0
1	9/26	14:50	166	24	4.3	50.4	4.3	350,000	-	-	-	4	34
46	10/4	8:30	155	20	5.7	62.1	2.7	93,000	4.0	5.1	7.0	4	58
B					Ebb Tide								High Tide
125	10/12	9:10	200	15	0	0	-	-	-	-	-	4	23
112	10/11	9:00	200	15	0	0	10.1	430,000	10.5	-	6.4	5	16
11	9/27	9:30	166	25	0	0	10.2	130,000	12.0	-	6.4	5	27
101	10/10	8:45	163	14	0	0	10.8	930,000	8.3	-	6.3	6	10
					Flood Tide								Low Tide
90	10/9	9:05	160	15	0	0	11.7	930,000	12.8	-	6.4	0	29
42	10/3	16:10	132	23	0.7	8.1	2.0	93,000	12.2	11.9	6.6	1	23
79	10/8	9:30	144	19	0	0	10.7	4,600,000	13.5	13.0	6.0	2	01
68	10/6	8:45	160	23	0	0	5.8	11,000,000	14.1	14.1	6.0	3	31
57	10/5	8:40	132	23	0	0	5.4	23,000	14.3	13.7	6.4	4	20
2	9/26	14:40	166	24	0	0	6.7	33,000	-	-	-	4	24
47	10/4	8:55	155	21	0	0	3.8	23,000	10.9	14.0	6.6	5	23

Appendix "A"

RAPPAHANNOCK RIVER INVESTIGATION

Tabulation of Individual Results

Sampling Station & No.	Date	Time	Stream Discharge (cfs)	Water Temp. °C.	Dissolved Oxygen ppm	Dissolved Oxygen % Sat.	5-Day B.O.D. ppm	Coliforms MPN/ 100 ml.	Chlorides Depth 3'	Chlorides Depth 10'	pH Depth 3'	Time From High Tide h	Time From High Tide m
					Ebb Tide								
C													
126	10/12	9:40	200	15	0	0	6.8	11,000,000	12.4	-	6.4	4	53
113	10/11	9:30	200	15	0	0	5.4	4,600,000	11.9	-	6.2	5	46
102	10/10	9:20	163	15	0	0	4.2	4,600,000	13.2	-	6.1	6	45
					Flood Tide								
												Low Tide	
41	10/3	15.45	132	23	3.5	40.3	5.0	1,500	10.8	10.0	6.8	0	58
91	10/9	9:45	160	17	0.8	8.2	2.5	240,000	12.2	-	6.2	1	09
80	10/8	10:05	144	19	2.5	26.7	0.9	360	11.5	11.5	6.6	2	36
69	10/6	9:15	160	23	1.9	21.9	1.4	91	11.0	10.6	6.7	4	01
3	9/26	14:25	166	22	1.4	15.8	5.7	22,000	7.2	-	6.8	4	09
58	10/5	9:10	132	22	1.8	20.4	1.2	430	10.9	10.2	6.8	4	50
48	10/4	9:20	155	21	2.2	24.5	1.7	360	7.3	9.0	6.7	5	48
D					Ebb Tide								
												High Tide	
59	10/5	9:40	132	22	4.8	54.4	1.2	1,500	8.7	8.1	7.0	0	33
49	10/4	9:50	155	21	4.9	54.5	1.1	930	7.9	7.7	6.8	1	29
127	10/12	10:20	200	19	3.0	32.1	0.5	1,100	10.7	-	6.7	6	08
					Flood Tide								
												Low Tide	
114	10/11	10:30	200	15	2.7	26.6	0.5	430	9.3	-	6.7	0	28
40	10/3	15:15	132	23	3.7	42.6	1.4	430	9.8	8.1	6.7	1	03
103	10/10	10:15	163	16	2.7	27.1	0.8	2,300	9.9	-	6.7	1	10
92	10/9	11:20	160	19	3.0	32.1	1.2	230	8.1	-	6.8	3	19
81	10/8	11:05	144	20	4.6	50.2	1.4	230	9.0	8.0	6.9	4	11
4	9/26	14:05	166	22	4.3	48.7	1.1	45	6.4	-	6.8	4	24
70	10/6	9:45	160	22	4.9	55.5	1.4	430	9.3	8.0	6.9	5	06

Appendix "A"

RAPPAHANNOCK RIVER INVESTIGATION

Tabulation of Individual Results

Sampling Station & No.	Date	Time	Stream Discharge (cfs)	Water Temp. °C.	Dissolved Oxygen ppm	Dissolved Oxygen % Sat.	5-Day B.O.D. ppm	Coliforms MPN/ 100 ml.	Chlorides Depth 3'	Chlorides Depth 10'	pH Depth 3'	Time From h	Time From m
E					Ebb Tide								
												High Tide	
71	10/6	10:25	160	23	7.1	81.8	1.3	430	7.6	7.0	6.9	0	26
60	10/5	10:20	132	22	7.1	80.4	1.4	2100	8.1	7.9	7.0	1	13
50	10/4	10:30	155	21	6.9	76.8	1.3	2300	5.1	7.9	6.8	2	09
					Flood Tide								
												Low Tide	
39	10/3	14:30	132	23	7.6	87.6	3.7	230	8.4	7.4	6.9	0	08
128	10/12	11:10	200	18	7.1	74.4	1.0	1100	8.6	-	6.8	0	16
115	10/11	11:05	200	15	6.8	67.0	1.1	430	9.3	-	6.7	1	03
104	10/10	10:55	163	16	6.8	68.3	1.1	1500	7.4	-	6.8	1	50
5	9/26	13:45	166	22	6.6	74.7	1.4	40	6.0	-	6.8	4	04
93	10/9	12:05	160	19	7.2	77.0	1.5	750	7.0	-	6.9	4	04
82	10/8	11:45	144	19	6.7	71.7	1.3	4300	7.3	6.2	7.0	5	51
F					Ebb Tide								
												High Tide	
72	10/6	11:00	160	24	8.1	95.0	1.6	930	6.4	7.0	7.0	1	01
61	10/5	10:55	132	23	7.4	85.2	1.4	2400	7.6	6.2	7.0	1	48
51	10/4	11:05	155	21	7.7	85.6	1.5	4300	5.2	5.8	6.9	2	44
38	10/3	13:45	132	24	7.9	92.6	5.6	930	7.1	7.0	6.8	6	07
					Flood Tide								
												Low Tide	
116	10/11	11:45	200	17	7.2	73.9	1.0	930	7.1	-	6.8	1	43
105	10/10	11:40	163	16	7.3	73.4	1.3	750	6.6	-	6.8	2	35
6	9/26	13:15	166	22	7.7	87.2	1.5	330	6.0	-	6.8	3	34
94	10/9	12:35	160	20	7.4	80.7	1.2	930	6.9	-	6.9	4	34
83	10/8	12:20	144	22	7.5	84.9	1.3	930	6.7	6.6	7.1	5	26

RAPPAHANNOCK RIVER INVESTIGATION

Appendix "A"

Tabulation of Individual Results

Sampling Station & No.	Date	Time	Stream Discharge (cfs)	Water Temp. °C.	Dissolved Oxygen ppm	Dissolved Oxygen % Sat.	5-Day B.O.D. ppm	Coliforms MPN/100 ml.	Chlorides Depth 3'	Chlorides Depth 10'	pH Depth 3'	Time From h	Time From m
G					Ebb Tide								High Tide
95	10/9	13:15	160	18	7.9	82.8	1.6	430	8.1	8.8	7.0	1	08
84	10/8	12:55	144	20	7.6	82.9	1.4	430	9.5	10.0	7.1	2	06
73	10/6	11:30	160	25	9.6	14.5	3.3	930	10.9	-	7.0	2	51
62	10/5	11:30	132	24	7.7	90.3	1.4	930	7.7	7.8	7.0	3	43
52	10/4	11:40	155	21	7.6	84.5	1.3	750	6.1	6.0	6.9	4	39
					Flood Tide								Low Tide
37	10/3	13:05	132	23	8.4	96.8	1.7	930	6.6	6.6	7.0	0	13
117	10/11	12:20	200	18	7.6	79.7	1.3	2300	7.0	6.9	6.8	3	38
106	10/10	12:15	163	16	7.6	76.4	1.3	930	6.2	8.0	6.9	4	30
7	9/26	13:00	166	23	7.9	91.0	0.9	170	4.4	-	6.8	4	38
H					Ebb Tide								High Tide
96	10/9	13:50	160	18	8.7	91.2	1.9	91	30.2	32.9	7.1	1	43
85	10/8	13:25	144	20	8.2	89.4	1.6	430	32.6	22.1	7.1	2	36
74	10/6	12:05	160	24	8.3	97.3	1.8	73	32.0	33.7	7.1	3	26
63	10/5	12:00	132	23	7.8	89.9	1.5	230	18.5	17.1	7.1	4	13
53	10/4	12:05	155	21	8.0	89.0	1.6	390	17.1	16.3	7.0	5	04
36	10/3	12:25	132	26	8.2	100.0	1.6	230	10.3	12.9	6.9	6	07
					Flood Tide								Low Tide
118	10/11	13:00	200	17	8.6	88.3	1.6	91	31.5	32.3	7.0	4	18
8	9/26	12:40	166	25	8.2	97.8	0.8	110	10.4	-	6.6	4	19
107	10/10	12:55	163	16	8.4	84.4	1.7	140	29.0	31.0	7.0	5	10

RAPPAHANNOCK RIVER INVESTIGATION

Appendix "A"

Tabulation of Individual Results

Sampling Station	Date 1951	Stream Discharge cfs	Water Temp. °C.	Dissolved Oxygen ppm	Dissolved Oxygen % Sat.	5-Day B.O.D. 20° C. ppm	Coli-forms MPN/ 100 ml.	Chlo-rides ppm	pH
I	9/27	166	22	8.2	92.9	1.1	20	2.0	7.1
	9/28	139	17	8.0	82.1	1.0	130	2.2	7.0
	10/1	142	18	9.1	95.4	1.1	45	2.8	7.2
	10/2	132	18	8.7	91.2	0.8	91	5.0	7.1
	10/4	155	21	8.6	95.7	0.7	91	2.0	7.1
	10/5	132	21	10.4	115.7	-	36	3.2	7.2
	10/6	160	21	8.5	94.5	0.7	230	2.5	7.1
	10/9	160	18	8.6	90.1	0.8	91	2.3	7.1
	10/10	163	13	9.6	90.6	0.6	91	3.0	7.1
	10/12	200	14	9.9	95.5	0.7	230	2.8	6.8
J	9/26	53	20	9.1	99.2	0.7	790	2.0	7.0
	9/27	71	23	8.9	102.5	0.5	1100	2.2	7.1
	9/28	66	21	8.8	97.9	0.8	2300	2.2	7.0
	10/1	61	20	10.0	109.0	1.0	1400	3.0	7.2
	10/2	83	24	10.1	118.4	0.5	430	1.5	7.2
	10/11	75	15	10.9	107.4	0.8	2400	2.1	6.9
	10/12	77	14	11.1	107.0	0.5	230	2.7	6.9
K	9/26	45	19	10.1	108.0	0.8	<20	2.0	7.1
	9/27	45	23	9.5	109.4	0.6	330	2.4	7.1
	9/28	45	26	9.2	111.9	0.9	1300	2.2	7.1
	10/1	41	21	10.1	112.3	0.9	230	2.8	7.1
	10/2	41	25	9.8	116.9	1.2	230	2.7	7.2
	10/11	62	14	10.2	98.4	0.7	430	2.9	6.8
	10/12	58	15	10.4	102.5	0.4	330	1.9	7.0
M	9/27	166	22	7.7	87.2	0.8	170	2.0	7.0
	9/28	139	19	7.9	84.5	0.6	110	2.0	7.1
	10/1	142	18	8.5	89.1	0.7	170	2.4	7.1
	10/2	132	19	8.8	94.1	0.7	150	3.3	7.1
	10/3	132	22	9.0	101.9	0.9	150	1.8	7.1
	10/4	155	20	8.6	93.8	1.0	150	2.2	7.1
	10/8	144	21	7.4	82.3	0.6	150	3.0	7.0
	10/9	160	19	7.7	82.4	0.7	430	2.1	6.9
	10/10	163	14	8.4	81.0	0.6	430	4.1	6.8
	10/11	200	16	8.8	88.4	0.5	150	2.0	6.9
N	10/1	61	20	10.0	109.0	0.7	93	2.1	7.2
	10/2	83	20	10.0	109.0	0.5	93	2.1	7.2
	10/5	61	24	9.3	109.0	0.9	230	3.0	7.2
	10/6	37	24	8.6	100.8	0.8	91	3.0	7.1
	10/8	68	19	8.2	87.7	0.6	430	2.6	7.1
	10/11	75	15	10.1	99.5	0.6	390	3.1	6.9
	10/12	58	15	10.4	102.5	0.4	330	1.9	7.0

RAPPAHANNOCK RIVER INVESTIGATION

Appendix "A"

Tabulation of Individual Results

Sampling Station	Date 1951	Stream Discharge cfs	Water Temp. °C.	Dissolved Oxygen ppm	Dissolved Oxygen % Sat.	5-Day B.O.D. 20° C. ppm	Coli-forms MPN/ 100 ml.	Chlo-rides ppm	pH
0	10/1	142	17	9.1	93.4	0.6	78	2.2	7.1
	10/2	132	19	9.3	99.5	0.6	36	4.8	7.2
	10/3	132	20	9.0	98.1	1.0	36	2.6	7.2
	10/5	132	24	8.9	104.3	0.7	150	3.0	7.2
	10/6	160	22	8.6	97.4	0.8	430	2.5	7.1
	10/8	144	20	8.4	91.6	0.4	930	3.2	7.1
	10/9	160	18	8.9	93.3	0.7	91	2.2	7.1
	10/10	163	14	9.7	93.5	0.8	150	3.0	7.0
	10/11	200	15	10.0	98.5	0.6	930	1.9	6.9
	10/12	200	15	10.4	102.5	0.6	790	1.8	6.9

Appendix "A"

RAPPAHANNOCK RIVER INVESTIGATION
Tabulation of Individual "DO" Results
Sampling Stations and Substations

Time From Station "A"	Q c.f.s.	A	A1	A2	A3	A4	A5	A6	A7	B	B1	B2	B3	B4	B5	B6	C	C1	C2	C3	D	Date	Temp.
High Tide										**Ebb Tide**													
3h 43m	200	8.1	4.2	2.0	0.8	0	0	0	0	0	0	0	0	0	0	0	0	0	0.4	2.0	3.0	10/12	14°C.
4h 46m	200	8.0	6.2	1.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.8	2.1	2.7	10/11	15°C.
5h 40m	163	7.5	7.3	4.8	2.3	0	0	0	0	0	0	0	0	0	0	0	0	0	1.6	2.3	2.7	10/10	14°C.
Low Tide										**Flood Tide**													
0h 6m	160	7.0	7.8	3.0	1.5	0	0	0	0	0	0	0	0	0	0	0	0.8	-	-	-	2.7	10/9	16°C.
1h 11m	144	6.3	2.8	0.4	0	0	0	0	0	0	0	0	0	0.5	1.9	2.8	2.5	-	-	-	4.6	10/8	19°C.

Appendix "A"

RAPPAHANNOCK RIVER SURVEY

Dissolved Oxygen Data

Station	River Mileage	Average Dissolved Oxygen ppm	Average Water Temp. °C.
	DOWNSTREAM STATIONS		
A	107.2	6.8	20
A-1	106.9	5.7	-
A-2	106.6	2.3	-
A-3	106.4	0.9	-
A-4	106.2	0.2	-
A5	105.9	0	-
A6	105.5	0	-
A7	105.2	0	-
B	104.8	0.1	20
B1	104.4	0	-
B2	104.1	0	-
B3	103.6	0	-
B4	103.0	0.1	-
B5	102.6	0.4	-
B6	102.0	0.6	-
C	101.6	1.4	19
C1	101.0	-	-
C2	100.4	-	-
C3	99.0	-	-
D	97.7	3.9	20
E	92.3	7.0	20
F	87.3	7.6	21
G	82.7	8.0	21
H	77.9	8.3	21

Station	River Mileage	Average Dissolved Oxygen ppm	Average Water Temp. °C.
	UPSTREAM STATIONS		
M	+1.5	8.3	19
I	+4.4	9.0	18
O	+6.4	9.2	18
K	+35.3	9.9	20
	RAPIDAN RIVER		
Mouth of Rappahannock	15.2	-	-
N	29.4	9.5	20
J	44.8	9.8	20

APPENDIX B

Appendix "B"

RAPPAHANNOCK RIVER INVESTIGATION
Mean Daily Discharge, in Second-Feet
During Survey Period

U. S. G. S. Gaging Station	September 1951						October 1951											
	25	26	27	28	29	30	1	2	3	4	5	6	7	8	9	10	11	12
Rapidan River (near Culpeper)	90	53	71	66	58	52	61	83	55	86	61	37	66	68	100	78	75	77
Rappahannock River (Kellys Ford)	46	45	45	45	44	42	41	41	43	43	42	41	42	44	50	62	62	58
Rappahannock River (Near Fredericksburg)	134	166	166	139	150	142	142	132	132	155	132	160	139	144	160	163	200	200

APPENDIX "C"

Appendix C

Waste Treatment Plants

Conditions in the Rappahannock River can be corrected either by a high degree of treatment of sewage and industrial waste, or by lesser treatment combined with an increase in the minimum flow of the stream. As a matter of policy, it is customary to credit any flow increase with the difference in cost between the high degree of treatment required without flow regulation and the lesser treatment which would be satisfactory in connection with a greater flow. Three types of treatment have been given consideration for Fredericksburg, namely: secondary treatment which can be depended upon to accomplish an 85% purification, chemical treatment which can be depended upon to accomplish a 70% purification, and primary treatment which can be depended upon to accomplish a 35% purification. Cost estimates have been prepared for these three types of treatment in order that the increase in cost of one treatment over the next less efficient treatment can be determined, to be designated as a benefit credited to stream regulation.

In determining the design sizes, provision has been made for accepting industrial wastes from Fredericksburg and vicinity. For the purpose of this report, it is assumed that industry and the City will combine on any project for stream improvement and thus secure possible economies usually attainable through operation of a single treatment plant. While detailed studies may indicate that combination treatment is not feasible or that lower over-all costs will result if separate treatment plants are built, the method used here is believed to be sufficiently accurate for the purposes involved.

Estimates of treatment costs have been based on cost experience at other places rather than on the preliminary design of specific treatment works for

Fredericksburg. The principal points of present interest are the differences in cost between various types of treatment on an annual basis, including operating charges, rather than the total installation cost of individual types of treatment. Local characteristics such as difficult sewer construction may add constant costs to all figures but will have little effect on cost differences.

The estimates of cost used in the 1943 report were projected to 1950 costs by use of Engineering News-Record index of costs.

The 400 c.f.s. no-damage-flow assumes secondary treatment or 85% reduction of pollution load by an actual treatment plant and furnishes sufficient dilution for the remaining 15 per cent of the load. This permits a 5.0 ppm dissolved oxygen content in the stream.

If additional flow could be furnished to satisfy the oxygen demand of another 15 per cent of the present pollution load, a chemical precipitation plant would be sufficient to place the river in a satisfactory condition. This additional flow, then, would be worth the difference between the cost of owning and operating the secondary treatment plant under the conditions assumed in the preceding paragraph and the cost of owning and operating a chemical precipitation plant. This cost (or benefit) was estimated to be $18,500 annually.

Similarly, if a further increase in low flows could be furnished to treat a total of 65 per cent of the pollution load, the effect would be that of secondary treatment and at the cost only of a primary treatment plant. This additional flow, then, would be worth the difference between the cost of owning and operating a secondary treatment plant, and owning and operating a primary treatment plant. This cost (or benefit) was estimated to be

$39,200 annually.

The incremental benefit of $1200 per month was computed by deducting the sum of the amortization cost of a chemical plant plus the operation cost of a primary plant from the total annual charge of a chemical plant and dividing that remainder by 12 months. This was based upon the premise that a chemical plant could be operated as a primary treatment plant when high flows were available; although when low flows occurred, the plant must be used as a chemical treatment plant.

This basis for estimating waste treatment costs gives values believed to be conservatively low because of the industrial wastes involved. There are no known data showing the rates at which process wastes from American Viscose Corporation may be stabilized. However, in prosecuting a pollution abatement program this industry would be expected to inaugurate process changes and possibly new processes to reduce the concentration of the wastes. Residual wastes would probably yield to biological treatment following neutralization. The principal oxygen-consuming material in these trade wastes is believed to be hemicellulose removed from the wood pulp by means of caustic. The rate of stabilization of such organic material is relatively low as compared with domestic sewage.

APPENDIX D

RAPPAHANNOCK RIVER POLLUTION INVESTIGATION

Biological Studies on the Rappahannock and Pamunkey Rivers

Charles M. Weiss
Biologist
U.S. Public Health Service*

These studies were carried out in conjunction with a chemical and bacteriological investigation of the Rappahannock River performed by a Field Survey Crew of the Environmental Health Center, U.S. Public Health Service, R. Vanderhoof in charge. The work of the Field Survey Crew was at the request of the Corps of Engineers who desired an assessment of pollution in the river and the benefits to be derived from low water regulation from a proposed dam on the Rappahannock River.

The biological studies are intended to supplement the chemical and bacteriological information. The types, numbers and distribution of aquatic organisms are helpful in demonstrating the extent and degree of pollution in a stream. The biological studies on the Rappahannock and Pamunkey Rivers were limited to a sampling of bottom organisms. This type of biological information is particularly useful where there are fluctuations in pollution discharges or river flow or river oscillations due to tides. In addition to the sampling of this investigation there are extensive plankton and fisheries collections available from the sections of the rivers under study. These collections were made by the Virginia Fisheries Laboratory over a 4-5 month period preceeding the current studies. The bottom samples round out the available biological information on these rivers.

Bottom samples were taken with a Peterson dredge at all stations on the Rappahannock River downstream of Fredricksburg, Virginia on the survey of October 2, and 3, 1951. The upstream stations were sampled by hand by random collections from appropriate bottom materials. The dredged samples were sieved in the field through a 30 mesh screen. Relative estimates were made of the organisms present at all stations and specimens of each type were taken and preserved for specific identification. The physical characteristics of the river bottom were described at each station. The collections were made under optimum river conditions for determining the effects of pollution, following an extended period of low flow.

In addition to the field sampling from the Rappahannock River during the first week in October, a second series of samples

* Division of Water Pollution Control
North Atlantic Drainage Basins

Reproduced from best available copy.

were taken one month later on November 6. These samples were taken at a series of representative stations for comparison with the data of the October survey. Eleven stations in all were resampled. This survey was carried out from boat facilities provided by the Virginia Fisheries Laboratory. The bottom samples were taken with an Ekman dredge and a quantitative analysis made of the bottom organisms.

In view of the natural changes in the ecology of the tidal streams it was felt that a survey of a non-polluted stream which would duplicate the ecology of the Rappahannock, in its tidal sector, would provide information that would help to evaluate the considerable fluctuations in numbers of bottom organisms that were found on the Rappahannock. For this purpose the Pamunkey River, flowing parallel to and a few miles south of the Rappahannock was selected. Eleven stations were sampled on the Pamunkey River at locations coinciding with stations of the Virginia Fisheries Laboratory and in approximately the same length of river as the polluted and recovery zone of the Rappahannock. This is a distance extending from the head of tide downstream for 18-20 miles. Boat facilities were again provided by the Virginia Fisheries Laboratory. The bottom samples from the Pamunkey were sampled and analyzed quantitatively.

The results of these studies are summarized for each river in a series of tables. These describe the physical characteristics of the river bottoms at the sampling stations, the general types and numbers of bottom organisms at the sampling stations and the specific identifications of aquatic organisms and stations at which they were encountered.

There are no significant sources of pollution on the Pamunkey River and it served as a control for the Rappahannock River. There are two principal pollution discharges on the Rappahannock in the area under study, one from the city of Fredricksburg, Virginia consisting solely of sanitary waste with a daily population equivalent (B.O.D.) of about 17,000 and another from a large industrial operation with a daily population equivalent (B.O.D.) of about 59,000. At present neither discharge receives any treatment. The effluent locations are noted on the map of the Rappahannock River. Sampling stations, A,B,C,D,E,F,G, and H,K,N, and O, as noted on this map, are the same locations as used by the Environmental Health Center Field Survey for their sampling points. The stations downstream of Fredricksburg also coincide with stations of the Virginia Fisheries laborabory studies. Stations noted A-1, A-2, etc. are supplementary stations used in the biological studies.

At the twenty-eight stations sampled. in the October survey on the Rappahannock River from Fredricksburg downstream, all but one had a soft mud bottom usually overlying a base of coarser sand.

(Table 1) Station D-6 at a sharp narrow bend in the river, had a pebbly bottom apparently resulting from the scouring action of the water removing the finer materials at this point. The bottoms of the upstream stations usually consisted of soft muds in the back eddies and hard pebbly bottoms in the riffles. The layers of the dredged bottom samples all contained varying amounts of natural organic matter in the form of plant debris. At some stations this plant debris in the subsurface layers comprised a large proportion of the total sample volume. In the stretch of the Rappahannock River from stations A-3 to B-4, a distance of 4.1 miles (nautical)* the surface layer of the river bottom was black with a soupy sludge like consistency. At some points in this section, an oily irridescent film was noted on the surface of the bottom mud. The river bottom between stations A-3 and B-4 appeared to be under anerobic conditions and the area coincided with the zone of maximum pollution effect as indicated by the low oxygen values obtained by the Field Survey.

The fauna and flora sampled from and observed in the Rappahannock and Rapidan Rivers, upstream from Fredricksburg, indicated a clean stream free of pollution. There were a variety of plants and animals at each station with no unusual dominance of any one type. Snails were noted at stations N and O in considerable number but were all of gill breathing species, which require adequate dissolved oxygen. (Tables 2 and 3).

From Fredricksburg downstream, the numbers and types of bottom aquatic organisms presented a typical picture of response of the biota of a stream to heavy pollution. At station A, above the pollution effluents the bottom showed no evidence of obvious pollution, but no bottom organisms were noted in the samples taken. However, the physical characteristics of this station were not conducive to a large bottom population, consisting of a thin silt layer over very coarse sand. The next two stations A-1 and A-2, also upstream from the first source of pollution, the effluent from the city of Fredricksburg, are apparently subjected to some contributions of organic matter due to the tidal movement of the river. A few tubificid worms and chironomid larvae were noted in the bottom sample taken at this station.

Stations A-3 and A-4, opposite and below the first source of pollution, respectively, had only a few tubificid worms in the bottom sample and from this point downstream to station B-4 the bottom samples showed a paucity of organisms. At station A-5 only a snail (Physa heterostropha), in very few numbers, was noted whereas at station B another species of snail (Helisoma anceps) and a very few specimens of the freshwater clam (Musculium transversum) were found in addition to tufts of the blue-green algae Oscillatoria sp. on the surface of the mud. All these organisms are pollution tolerant types.

---

* Distances on the tidal sectors of the Rappahannock and Pamunkey Rivers are measured in nautical miles since the distance and location net established by the Chesapeake Bay Institute for the entire Chesapeake Bay area is measured on this base.

Reproduced from best available copy.

At the next station there had been a set of the clam M. transversum, but growth had been apparently limited. Six-tenths of a mile downstream at station B-2 the same species of clam was again found but here the specimens were of mature size, and of more significance they were actively feeding. The shells of this species of clam being translucent, ingested material can be seen, particularly when of a contrasting color. In this case all the clams appeared to be black inside the shell since they had been ingesting the bottom mud to utilize the organic matter in the mud. This is noteworthy since the clams are gill breathers and require dissolved oxygen. Through station B-4 where the black bottom ended, "black" clams were noted. With the termination of the soupy black mud on the surface of the river bottom the numbers of the clam M. transversum increased enormously reaching a peak at station C-2 where the population was on the order of more than 1000 per sq. foot of bottom surface.

Paralleling the increase in the clam population, the chironomid larvae also increased. It is of interest to note that whereas the chironomid larvae were found at stations B-2 and B-3 and then again from station C through D-1 the tubificid worms did not appear again in the bottom samples until station C-4 after last being noted at station A-4. The tubificid worms continued to be found at nearly all downstream stations working over the natural organic debris while the larvae of the chironomid, Tendipes decorus (a red species) disappeared and were replaced at the farthest downstream stations by larvae of the chironomid, Clinotanypus sp., (a yellow species). At the one hard bottom station sampled, D-4, a planarian and a leech were found. A leech was also collected at station D-6. The downstream stations E through H were characteristic of non-polluted waters in that there were more types of aquatic organisms but each group was represented by fewer numbers. The larvae of the culicid fly, Chaeborus punctipennis, was noteworthy in the bottom samples since it has been reported as being tolerant of very low oxygen concentrations.

The resurvey of the Rappahannock carried out on November 6, 1951 showed that even within the month since the original sampling, changes had taken place in the distribution of the bottom organisms. The black bottom which previously had extended only to station B-4 was now noted to extend 1.5 miles further downstream as far as station C-2. This shift was most probably due to an increase in run-off resulting from a series of heavy rains. At station C-2, a sample taken near the shore brought up the black mud but another sample taken in the channel showed a sandy bottom. The distribution of organisms and their numbers on the resurvey are shown in Table 4. As in the original sampling, the largest clam population was found at station C-2 numbering about 2800 per sq. ft. of bottom in the second survey. The magnitude of this clam productivity is emphasized by comparison with samples reported

from the Illinois River. Richardson[1/] investigating the effect of pollution from the Chicago Drainage Canal on the Illinois River reported the largest M. transversum sample taken at 3496.9 per square yard. This is approximately a clam concentration of 388 per square foot, in comparison to the 2800 per square foot on the Rappahannock. In addition to the clam M. transversum, another species, Pisidium sp., was also present in considerable numbers, reaching a peak of 880 per sq. ft. However, this clam population consisted completely of young stages.

Of particular note in the changes of bottom organisms was the presence of the larvae of the midge, Chaoborus punctipennis at stations B-4 and C-2 in addition to stations F and H where it had been found on the first survey. Paralleling the downstream shift in the black bottom considerable numbers of M. transversum were noted to have recently died, their shells were open but still hinged together or their soft parts were decomposing. Dead clams averaged about 30% of the total M. transversum population.

The control survey on the Pamunkey River showed both a difference in bottom characteristics and organism association from that found on the Rappahannock. Nearly all the bottoms sampled on the Rappahannock in the tidal sector were soft muds or clays over coarser sand whereas on the Pamunkey nearly all the bottoms sampled were fine to coarse sands. (Table 5).

Both in numbers and species the bottom organisms of the Pamunkey differed from that found on the Rappahannock. (Table 6 and 7). The dominant clam of the Rappahannock, M. transversum, was not encountered in any of the bottom samples taken. However, it may have been present but in so few numbers that it was not sampled. In contrast the considerably larger species Elliptio complanata was the dominant pelecypod on the Pamunkey River. This species was found over a distance of 7 miles from stations E through H reaching a peak in numbers at station G. An unusual concentration of these clams may be present near the south west shore of the Pamunkey at station J. Attempts to obtain a bottom grab at this point were unsuccessful. The heavy Peterson dredge would not dig in but would nip off a few clams at each lowering. There may be a clam "reef" at this point. The reported sample at station J was taken from a softer bottom toward the north east shore of the river.

1/ Richardson, Robert E. The small bottom and shore fauna of the Middle and Lower Illinois River and its connecting lakes, Chillicothe to Grafton; its valuation; its sources of food supply; and its relation to the fishery. Bull. Illinois State Laboratory of Natural History. XIII. 363-352. 1919.

Overlapping at the upstream edge of the stretch of the Pamunkey River in which E. complanata occurred was a zone dominated by the snail, Lioplax subcarinata, This zone extended for 3.5 miles from stations D to G. This species was found in the first survey on the Rappahannock at stations D and D-1, just 3.3 miles from the edge of the zone of degradation and within the zone of recovery. This snail species is a gill breather and therefore requires dissolved oxygen in its immediate aquatic environment. There were no unusual numbers of organisms on the Pamunkey that are usually associated with severe pollution conditions.

It is of interest to note that the bottom sample taken at station G on the Pamunkey River contained a fossil shark tooth. This tooth was identified as belonging to a genus of sand sharks (Carcharias) and probably of Tertiary origin.

On both rivers two species of clams were the dominant bottom organisms. On the Rappahannock, M. transversum achieved the dominating role and on the Pamunkey, E. complanata. In comparison, on a numerical basis, the Rappahannock appeared to be the more productive river achieving in the peak sample about 2800 clams per square foot. However, comparison on a weight basis presents a different picture of productivity. Representative samples of the two species, indicated an average wet weight for M. transversum of .0937 gms. and 304.2 gms for E. complanata. Thus on a wet weight basis the productivity on the Pamunkey River based on the maximum clam sample was 12,168 gms per square foot but only 262.3 gms per square foot for the Rappahannock River. Although the Rappahannock productivity analysis accounts for only M. transversum, the young of other clam species present, Pisidium sp. was even smaller than M. transversum, averaging only about 1-1.5mm in largest dimension, and their contribution to the total productivity on a weight basis can be considered negligible. It appears that the contribution of nutrients to the Rappahannock River by the organic pollution enabled a surge in productivity. However, this was limited to pollution tolerant species and on a weight basis did not compare as well with the clam productivity of the non-polluted Pamunkey River.

In summary, based on the physical characteristics and the distribution and numbers of the bottom organisms in the Rappahannock River, the zone of degradation and decomposition early in October, extended from station A-3 to B-4, a distance of 4.1 miles (nautical). The zone of recovery extended from station C to about station E, a distance of 8.0 miles (nautical) and for the remainder of the river that was examined the bottom organisms did not appear to be materially affected by the upstream pollution. The comparatively short distances involved is of course a result of the tidal action in the river which tends to limit downstream movement of polluting materials and compresses the zones of pollution effects.

Reproduced from best available copy.

The unusual numbers of fresh water clams found in the Rappahannock River is of particular interest. These bottom organisms are present in the numbers observed due to the fact that an unusual food supply has developed which can support this large population, which itself is tolerant of pollution. In turn the clams are very actively working over the organic matter in the river bottom utilizing it as a source of food and simultaneously stabilizing the organic materials.

The enrichment of the Rappahannock River by organic pollution enabled the development of the enormous numbers of the clam M. transversum. However, this enrichment did not surpass the total clam productivity, on a weight basis, of the Pamunkey River. The natural productivity of the latter stream maintained a weight of clams, at the best station sampled, of more than 46 times that found on the Rappahannock River. It should be noted, however, that the pill clams belinging to the family Sphaeriidae serve as food for many species of fish. Thus the Rappahannock with the fish food chain supplemented by the enormous numbers of M. transversum may sustain a greater fish population than the Pamunkey along the comparable stretches of river.

Acknowledgement: This investigator wishes to acknowledge the identification service provided by the U.S. National Museum for most of the insect larvae and molluscs collected in these studies. Dr. Bobb Schaeffer of The American Museum of Natural History identified the shark tooth and Dr. Libbie H. Hyman of this same institution identified some of the other invertebrate forms.

Table 1

Rappahannock River Pollution Investigation
Biological Studies
October 2, 1951

BOTTOM CHARACTERISTICS

Station	River Mile**	Surface Layers: Color: Red or Brown	Color: Gray	Color: Black	Fine Silt	Mud	Sand	Pebbles	Plant Debris*	Sub-Surface Layers: Mud	Clay	Sand	Plant Debris*	Remarks
A	93.5	x			x				1			x	1	
A-1	93.3	x				x			1			x	1	
A-2	93.0	x				x			1			x	1	
A-3	92.9			x		x			1	x			1	
A-4	92.8			x		x			1	x		x	3	Top layers soupy, and oily
A-5	92.4			x		x			1	x		x	1	As A-4
B	91.3			x		x			1			x	1	As A-4
B-1	90.4			x		x			1			x	1	Surface mud soupy
B-2	89.8			x		x			1	x			1	As B-1
B-3	89.2			x		x			1	x			3	As B-1
B-4	88.8			x		x			1			x	1	As B-1
C	86.6		x			x			2			x	2	Subsurface layers dark coarse sand
C-1	87.8	x				x			1			x	1	As C
C-2	87.3	x				x			1			x	1	As C
C-3	86.7	x				x	x		1			x	3	
C-4	85.8	x				x	x		1			x	2	
D	85.2	x			x				1			x	1	
D-1	84.1	x			x				1	x			1	
D-2	83.1	x				x	x		1		x		1	
D-3	82.5	x				x			2			x	2	
D-4	82.1	x				x	x		2			x	3	
D-5	81.6	x				x	x		1			x	2	
D-6	81.3							x						
E	80.6	x			x	x	x		1			x	2	
E-1	78.2	x				x			1	x			2	
F	76.3	x			x	x	x		2			x	3	
G	72.3	x				x	x		1		x		3	
H	68.2	x				x			1		x		3	
K	35	x			x				1			x	2	
N	13***	x				x		x	1			x	1	
O	6.5							x						

* Approximate Quantity
1 - (1-10% of sample)
2 - (10-25% of sample)
3 - (25-50% of sample)

** Stations A through H downstream from Fredricksburg. River miles (nautical) from zero point at mouth of river. Stations K, N & O, upstream from Fredricksburg. Distances upstream in statute miles with zero point at Fredricksburg.

*** On Rapidan River. River miles measured from confluence with Rappahannock River.

Table 2

Rappahannock River Pollution Investigation
Biological Studies
October 2, 1951

BOTTOM ORGANISMS

Station	River Mile*	Tubificidae (Segmented worms)	Insect Larvae: Chironomidae	Insect Larvae: Other Dipterous Larvae	Snails: Prosobranchiata	Snails: Pulmonata	Clams: Unionidae	Clams: Sphaeriidae	Platyhelminthes (Flat Worms)	Hirudinae (Leeches)	Algae: Cyanophyceae	Algae: Chlorophyceae	Remarks
A	93.5												No organisms in sample
A-1	93.3	1											
A-2	93.0	1	1										
A-3	92.9	1											
A-4	92.8	1											
A-5	92.4					1							
B	91.3					1		1			1		Algae growing on bottom
B-1	90.4							1					Clams set but did not grow
B-2	89.8		1					1					Clams black from ingesting mud
B-3	89.2		1					1					Clams black
B-4	88.8							1					Clams black
C	88.6		1			1	1	2					
C-1	87.8		1					3			1		Algae growing on bottom
C-2	87.3		3				1	4					
C-3	86.7		3					3					
C-4	85.8	1	3					3					
D	85.2	2	2		1		1	3					
D-1	84.1	2	2		1			2					
D-2	83.1	1						2					
D-3	82.5	2						1					
D-4	82.1	1								1			Broken shell of Unionidae
D-5	81.6		1					1					
D-6	81.3					1			1	1			
E	80.6	1	2					1					
E-1	78.2	1	2	1				1					
F	76.3	1	1	1			1						
G	72.3	1	1	1									
H	68.2	1	1	2									
K	35			2									Many small fish
N	13			2	3							2	Many small fish
O	6.5			2	3							2	Many small fish

*Stations A through H downstream from Fredricksburg. River miles (nautical) measured from zero point at mouth of river. Stations K, N & O upstream from Fredricksburg. Distances upstream in statue miles from zero point at Fredricksburg. Station N is 13 miles up Rapidan River measured from confluence with Rappahannock River.

Numbers indicate estimated populations per square foot.
1, <10; 2, 10-100; 3, 100-1000; 4, >1000

Table 3

Rappahannock River Pollution Investigation
Biological Studies

October 2, 3, 1951

Organisms Collected in Bottom Samples

Organisms	Stations
Algae	
Cyanophyceae	
Oscillatoria sp.	B, C-1
Chlorophyceae	
Cladophora sp.	O
Spirogyra sp.	N, O
Ulothrix sp.	N, O
Turbellaria	
Dugesia tigrina	D-6
Annelida	
Tubificidae	A-1, A-2, A-3, A-4, C-4, D, D-1, D-2, D-3, D-4, E, E-1, F, G. H
Hirudinea	
Glossiphonia sp.	D-4, D-6
Mollusca	
Pelecypoda	
Anodonta cataracta Say	C-2
Elliptio complanatus (Solander)	G, F
Lampsilis ochraceus Say	C, D
Musculium transversum Say	B, B-1, B-2, B-4, C, C-1, C-2, C-3, C-4, D, D-1, D-2, D-3, D-5, E, E-1
Pisidium compressum Prime	B
Pisidium sp.	C, C-1, C-2, C-3, C-4, D
Gastropoda	
Ferrissia tarda Say	D-6
Goniobasis virginica (Gmelin)	N
Helisoma anceps (Menke)	B
Lioplax subcarinata (Say)	D, D-1
Mudalia carinata (Brugiere)	N, ●
Physa heterostropha (Say)	A-5, C

Table 3 (continued)

Rappahannock River Pollution Investigation
Biological Studies

October 2, 3, 1951

Organisms Collected in Bottom Samples

Organisms	Stations
Insecta	
Tendipedidae (Chironomidae)	
Tendipes decorus (Johannsen)	A-2, B-2, B-3, C-1, C-2, C-3, C-4, D, D-1, D-5, E, E-1
Clinotanypus sp.	E, E-1, F, G, H
Culicidae	
Chaeborus punctipennis (Say)	E-1, F, G, H
Hydropsychidae (Caddis flies)	
Hydropsyche sp.	K
Elmidae (Beetles)	
Macronychus sp.	K
Macronychus glabratus (Say)	K
Stenelmis sp.	K
Simsonia vittata (Melsh)	K
Bryozoa	
Plumatella sp.	D-6

Table 4

Rappahannock River Pollution Investigation
Biological Studies
November 6, 1951

BOTTOM ORGANISMS

Numbers per square foot

Station	River Mile	Tubifi-cidae	Chironomidae *Tendipes decorus*	Culicidae *Chaoborus punctipennis*	Unionidae *Ellipto complanatus*	Sphaeriidae *Musculium transversum*	*Psidium* sp.
B-2	89.8	8	4	0	0	4	0
B-4	88.8	300	60	72	0	152	40
C	88.6	500	240	0	0	160	32
C-2 Shore	87.3	560	16	24	0	480	350
C-2 Channel	87.3	0	0	8	0	2,800	880
C-3	86.7	1,020	8	0	0	735	290
D	85.2	200	240	0	0	240	88
D-3	82.5	170	32	0	4	28	16
E	80.6	160	24	0	4	8	0
F	76.3	100	90	8	0	0	0
G	72.3	0	20	0	0	0	0
H*	68.2	8	24	12	0	4	0

* One unknown genus of Unionicolidae (water mite) also collected.

Table 5

Rappahannock River Pollution Investigation
Biological Studies on the Pamunkey River
November 7, 1951

BOTTOM CHARACTERISTICS

Station	River Mile*	Color			Fine Silt	Mud	Clay	Fine Sand	Coarse Sand	Pebbles	Plant Debris**
		Red or Brown	Gray	Black							
A	68.0	x							x		1
B	66.2	x							x		2
C	64.3	x							x		2
D	62.9	x						x	x		2
E	61.2	x							x		2
F	60.2	x							x	x	<1
G	59.4	x							x		1
H	58.3	x						x	x		<1
I	57.2	x							x		1
J	54.2	x				x					3
K	50.7	x				x	x				1

* River miles (nautical) from zero point at mouth of river.

** Approximate Quantity
1 - (1-10% of sample)
2 - (10-25% of sample)
3 - (25-50% of sample)

Table 6

Pamunkey River Biological Studies

In Conjunction with the Rappahannock River Pollution Investigation

November 7, 1951

BOTTOM ORGANISMS

Numbers per square foot

Station	River Mile	Tubificidae	Chironomidae Tendipes decorus	Prosobranchiata Lioplax subcarinata	Pulmonata Menetus dilatatus	Unionidae Elliptio complanatus	Sphaeriidae Psidium abditum
A	68.0	50	4	•	0	0	0
B	66.2	5	0	0	0	0	0
C	64.3	24	16	0	4	0	0
D	62.9	28	32	16	0	0	0
E	61.2	8	20	52	0	17	4
F	60.2	0	0	0	0	16	0
G	59.4	48	12	16	0	55	4
H	58.3	0	0	0	0	4	0
I	57.2	15	4	0	0	24	0
J	54.2	0	0	0	0	6	0
K	50.7	0	•	0	0	0	0

Table 7

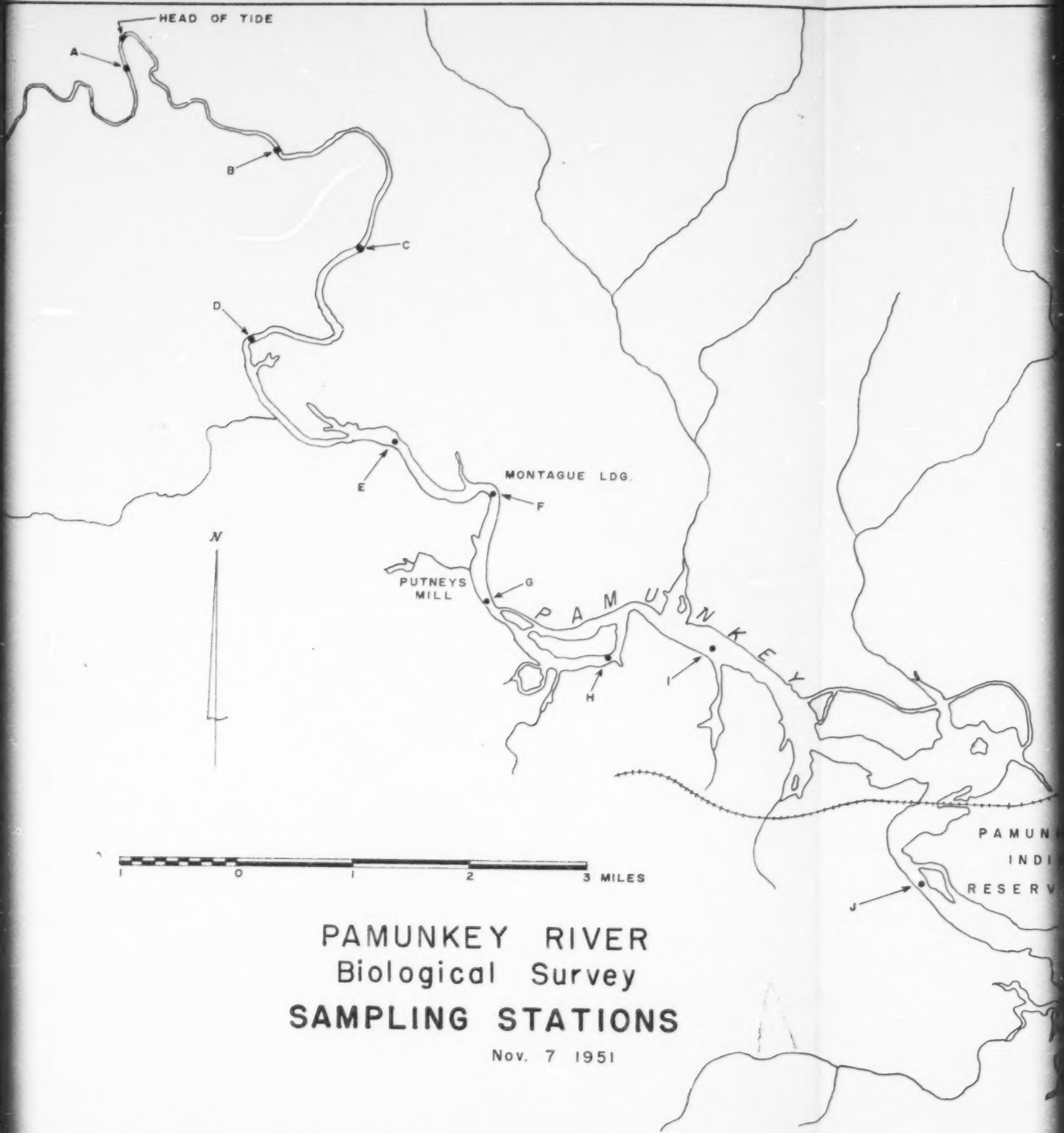
Pamunkey River Biological Studies

In Conjunction with the Rappahannock River Pollution Investigation

November 7, 1951

Organisms Collected in Bottom Samples

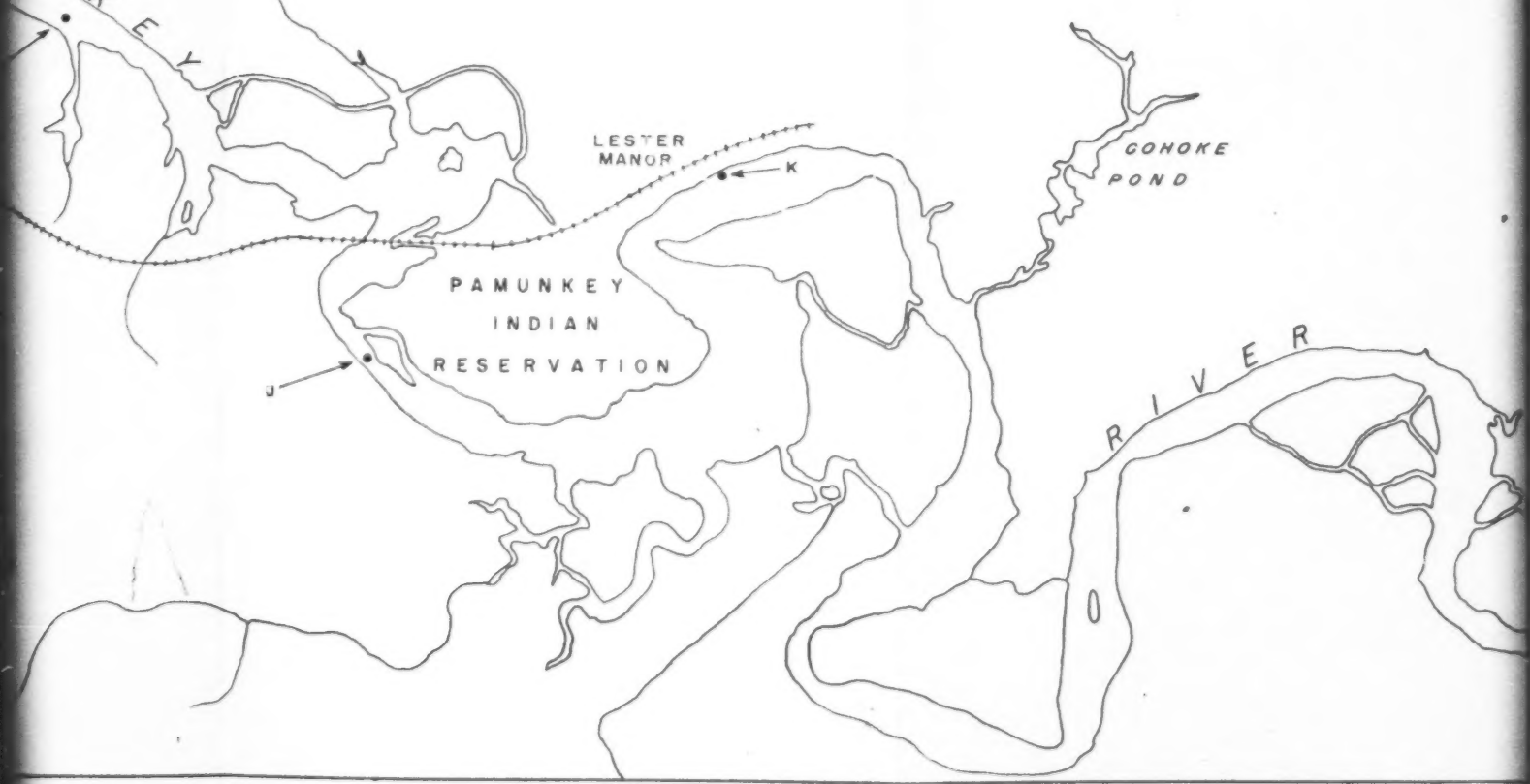
Organism	Station
Annelida	
Tubifex sp.	A, B, C, D, E, G, I
Limnodrilus sp.	A
Mollusca	
Pelecypoda	
Elliptio complanatus (Solander)	E, F, G, H, I, J
Psidium abditum Haldemen?	E, G
Gastropoda	
Lioplax subcarinata	D, E, G
Menetus dilatatus (Gould)	C
Insecta	
Trichoptera	
Genus sp.?	K
Ephemeroptera	
Hexagenia munda Eaton	D
Plecoptera	
Gomphus sp.	•

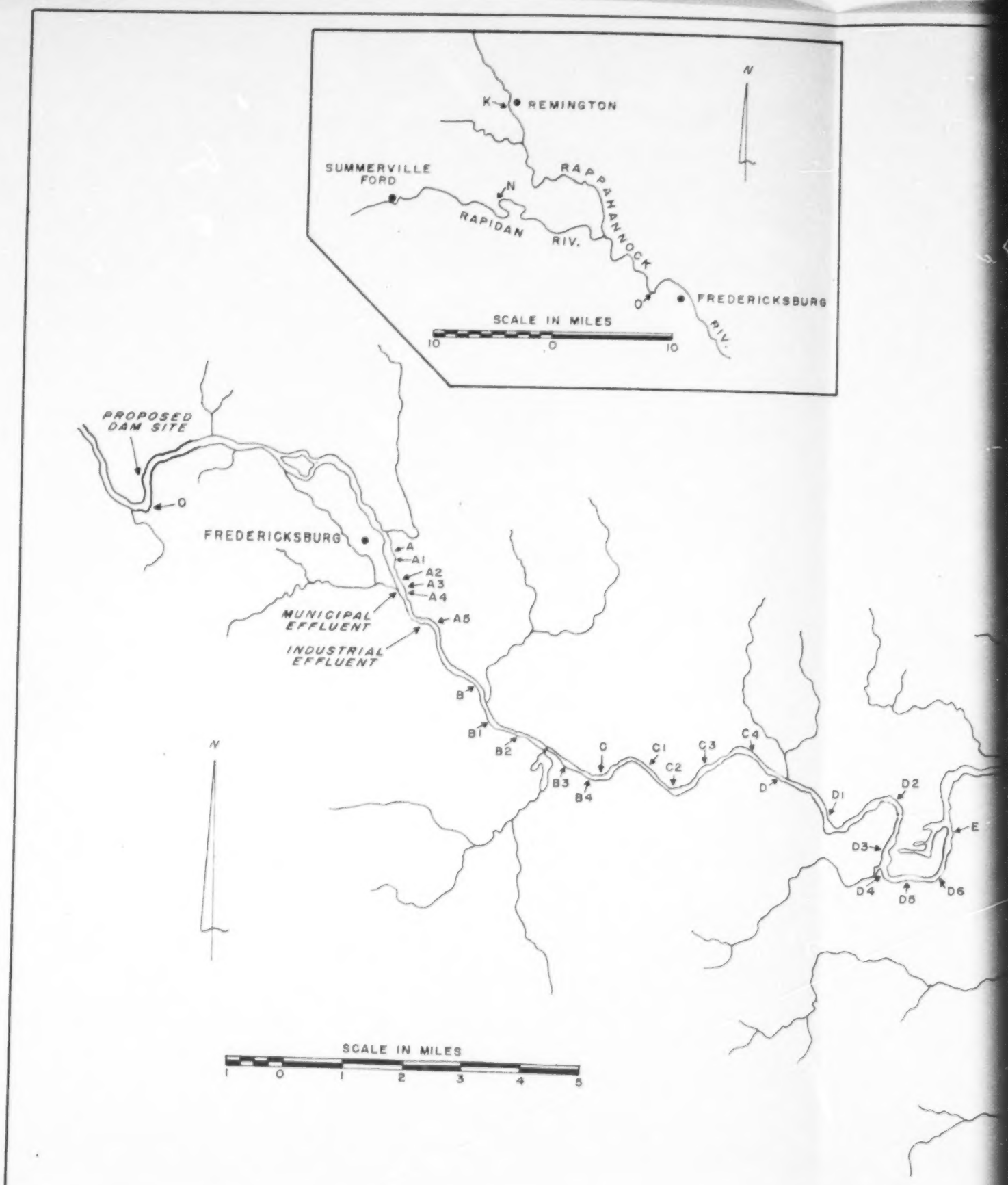


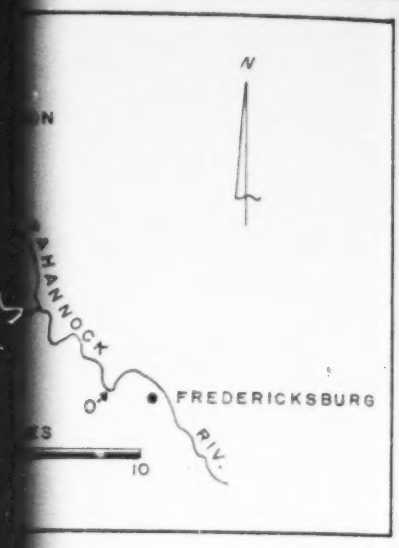
PAMUNKEY RIVER
Biological Survey
SAMPLING STATIONS

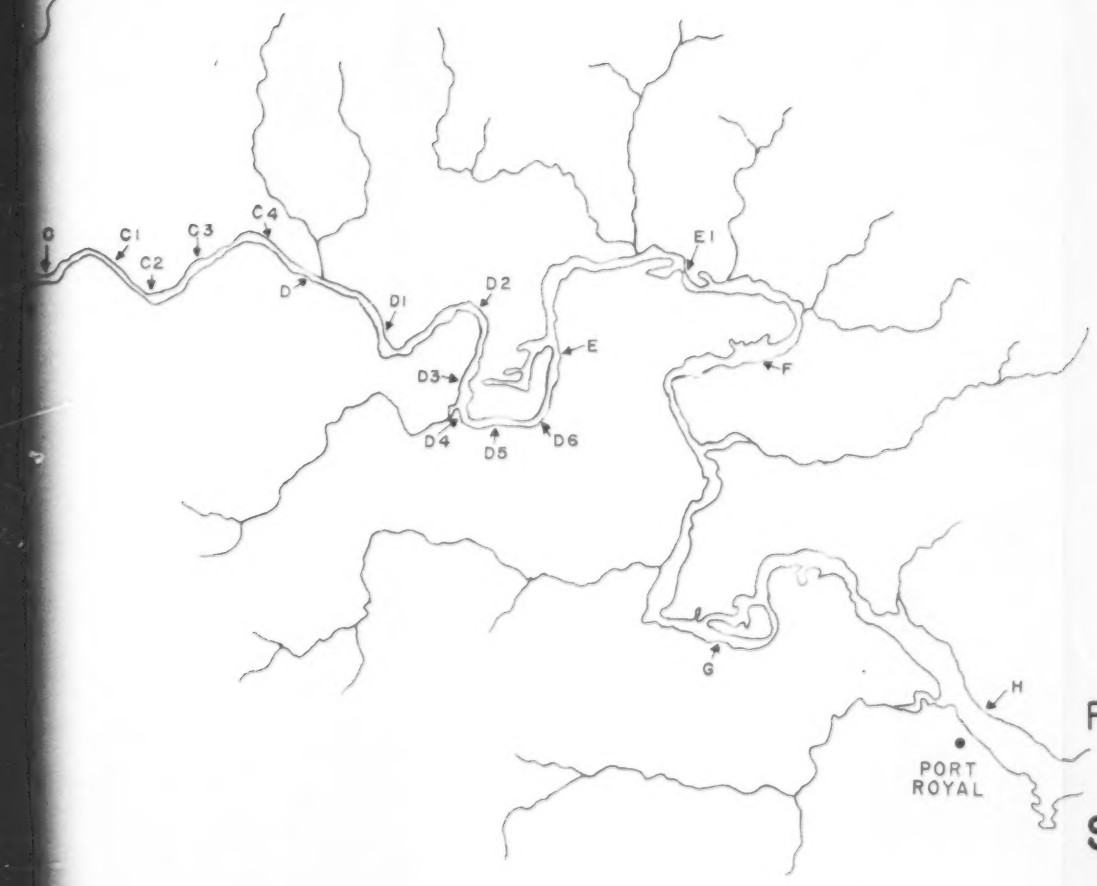
Nov. 7 1951

LOCATION MAP




N
K
REMINGTON
SUMMERVILLE FORD
N
RAPPAHANNOCK
RAPIDAN
RIV.
O
FREDERICKSBURG
RIV.
SCALE IN MILES
10
0
10
PROPOSED DAM SITE
O
FREDERICKSBURG
A
A1
A2
A3
A4
A5
MUNICIPAL EFFLUENT
INDUSTRIAL EFFLUENT
B
B1
B2
B3
B4
C
C1
C2
C3
C4
D
D1
D2
D3
D4
D5
D6
E
N
SCALE IN MILES
1
0
1
2
3
4
5





RAPPAHANNOCK RIVE
Biological Survey
SAMPLING STATION

Oct. 3-4 195